MODELING STREET TREES ON A STATEWIDE BASIS IN NEW YORK STATE

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Street trees are an integral component of livable, healthy communities providing ecosystem benefits and social and aesthetic amenities. Street tree inventory data provides detailed information about the structure and health of a street tree population and facilitates effective planning and management. Most communities lack an inventory, however, and the patchwork of data at the state level makes planning and management of urban and community forestry difficult for state officials. This dissertation proposes a methodology using street tree inventory data stratified and weighted by 1990 USDA Plant Hardiness Zone classes to estimate New York State's prevalent street tree species and genera, quantify statewide benefits provided by street trees, and identify statewide trends in the urban forest. Methods used are replicable by other states so officials in those states can obtain similar information.

Based on this methodology, *Acer* was found to be New York State's most prevalent street tree genus and *Acer platanoides* its most prevalent street tree species. Street tree numbers were estimated for the most prevalent genera and species. Species diversity increased with milder climate, but was found to be insufficient statewide, suggesting vulnerability to invasive pests such as the Asian Longhorned Beetle and Emerald Ash Borer. Analysis of trunk diameter profiles indicated an aging street tree population statewide requiring an increase in new plantings to maintain street tree numbers at current levels. Statistics for the youngest trees revealed increased plantings of small sized tree species relative to plantings of large and medium sized tree species regardless of overhead utility wires and planting location types. Benefits provided per street tree as calculated by i-Tree software did not vary by 1990 USDA Plant Hardiness Zone class, but significant differences were found by zone class in the number of street trees planted per unit of street length. Subsequent to preliminary findings, a number of test street tree inventories were conducted to evaluate whether statistics and trends at the zone class level would be found for the test inventories also. Test inventory statistics did not agree completely with preliminary statistics, but did confirm differences and trends found at the zone class level.

BIOGRAPHICAL SKETCH

Fred Cowett grew up in New York City and graduated from Harvard College in 1977 with a BA magna cum laude in History. After moving to Los Angeles and working for many years in the movie business, he moved to Ithaca, New York in 2001, earned an MLA from the Department of Landscape Architecture at Cornell University in 2004, and entered Cornell's Department of Horticulture in 2005 to pursue a PhD. He is married to Diana Riesman and parent to Theo and Nora.

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LIST OF ABBREVIATIONS

ALB	Asian Longhorned Beetle
ALIS	Accident Location Information System (New York State)
CARS	Community Accomplishment Reporting System
CDP	Census Designated Place (United States Census Bureau)
CFCC	Census Feature Class Codes (roads)
DBH	(Trunk) Diameter at Breast Height
DEC	New York State Department of Environmental Conservation
DLG	Digital Line Graph
EAB	Emerald Ash Borer
ECA	Evergreen Communities Act (Washington State)
FCC	Feature Class Codes (roads)
FIA	Forest Inventory Analysis (United States Forest Service)
FIPS	Federal Information Processing Standard
GIS	Geographic Information Systems
GNIS	Geographic Names Information System
GPS	Global Positioning System
LIDAR	Light Detection And Ranging (remote sensing)
LCL	Lower Confidence Level
LULC	Land Use Land Cover
MRLC	Multi-Resolution Land Characteristics
MTAIP	MAF/TIGER Accuracy Improvement Project
MTFCC	MAF/TIGER Feature Class Codes (roads)
NCDC	National Climatic Data Center
NLCD	National Land Cover Dataset

NRCS	National Resources Conservation Service
NYSUCFC	New York State Urban and Community Forestry Council
PPSM	Persons Per Square Mile
PRISM	Parameter-elevation Regressions on Independent Slopes Model (Oregon State University)
SDI	Simpson’s Diversity Index
STATSGO	State Soil Geographic
SUSI	Sample Urban Statewide Inventory (Indiana)
SWAT	Student Weekend Arborist Team (Cornell University)
TIGER	Topologically Integrated Geographic Encoding and Referencing (United States Census Bureau)
UCL	Upper Confidence Level
UFORHIC	Urban Forest Health Information Center
USDA	United States Department of Agriculture
VIF	Variance Inflation Factor

PREFACE

A treelined street with overarching branches creating a cathedral effect is an iconic image found on book covers, Christmas cards, and websites although the presence of trees alongside streets signifies different meaning to different people. For Bailey (1915), the street tree is an opportunity for "the townsman" to experience and remain connected to nature. For Gandy (2002), it is part of the "social production of nature" that legitimizes capitalism and the imposition of social order. These differences are not new and doubtlessly will continue. What is indisputable is the fact that the street tree is a ubiquitous feature in the settled landscape. However, defining what a street tree is can be problematic. As the phrase suggests, a street tree is a tree that grows alongside and is associated with a street. This definition may be too vague since it makes no distinction between settlement type (i.e. urban, suburban, or rural), land use type (i.e. residential, commercial, or agricultural), distance to the tree from the street, and management responsibility (i.e. publicly or privately maintained). More specificity may be required to better understand how to define a street tree, what they are, and why we should care about them. A brief look at their historical context may provide some insight.

The origin of the street tree has been traced to the planting of city walls in Europe to create promenades (Lawrence 1995) and to the forested pathways radiating outward from French royal gardens and into the neighboring villages and towns (Zube 1975). European cities typically lacked trees since there was little room to plant them and, if planted, trees were likely to be cut down since their wood was a source of fuel. Colonial American streets generally lacked trees due to other factors including concern for fire prevention (Zube 1973) and an unsentimental view of trees derived from the hard work required to clear forests in order to plant crops (Stilgoe 1982). By the late 18th century, however, civic concern over the poor aesthetic appearance of settlements in the newly formed United States led to tree planting in village commons and the creation there of formal promenades of rows of trees (Favretti 1982). These plantings were later extended outward from the commons into adjacent streets and walking along the treelined streets became a popular form of recreation and source of civic pride (Favretti 1982). Treelined streets proliferated in cities including New York City where most major streets by 1830 were planted with rows of trees on both sides (Zube 1973) although similar plantings were not meet with approval everywhere. In Keene, New Hampshire, for example, street tree plantings were temporary halted in 1850 because of citizen protests that the city was becoming too “countrified” and concern that trees would block business signs (Campanella 2003). Nevertheless, the planting of trees along streets in the United States continued unabated, spurred by the development of streetcar suburbs in the late 19th century and the City Beautiful movement of the Progressive era which valued street trees not simply for their aesthetics, but also as contributors to public health and human well-being (Karson 2007). These days, treelined streets have become a permanent feature of the settled landscape and street tree management has become a municipal concern with funds and personnel dedicated to their care and maintenance (Ricard 2005).

This brief history contains several themes including mediating the transition from agrarian to industrial society, the desire for civic improvement to temper development, the value of public space, and the promotion of human health.

Consistent in these themes is that the street tree functions as a public amenity providing valued benefits to communities irrespective of settlement type, land use type, distance from the street, or management responsibility. Street trees can consequently be seen as contributing to the “common weal,” acting in the interests and for the benefit of the majority of the general public. This community based function is lacking in the definition stated above and another definition is therefore proposed: a street tree is a tree growing in the public right-of-way for the benefit of the community. It is the street tree’s community based function and the benefits associated with it that justifies this dissertation. It is why we should care about modeling street trees on a statewide basis, about facilitating better planning and management of street trees at the statewide and local level, and about increasing public awareness and support for community forestry programs.

CHAPTER 1

INTRODUCTION

The phrase “can’t see the forest for the trees” implies that so much attention is paid to the details that the larger picture is lost. Therefore, to better understand the forest as a whole one needs to step back from focusing on individual trees. This phrase has special relevance to the field of urban forestry which has been defined in various ways including “all woody vegetation within the environs of all populated places, from the tiniest villages to the largest cities” (Grey & Deneke 1992), “all the vegetation in an urbanized area” (Rowntree 1995), and “the area in and around the places we live that has or can have trees” (Moll 1995). According to Jorgensen (1986) who is generally credited with coining the term, urban forestry, however it is defined, required delineation in order, first, to link shade trees in the city to the rural and uncultivated forests beyond it and, second, to transition tree management from arboriculture, the study of single tree cultivation, to a specialized branch of forestry that considered all the trees in the entire urban area. This “stepping back” from focusing on single trees to better see the forest they comprise, albeit an urbanized forest, has given urban forestry an ecological, systems based approach and positioned urban trees as significant contributors to green infrastructure and urban ecology. Nevertheless, since the urban forest consists at least in part of publicly managed trees that are planted, cultivated, and maintained, whether along street rights-of-way or in parks, cemeteries, etc., urban tree management has not shifted entirely away from arboriculture. Urban forestry therefore contains dual foci much like co-dominant leaders in a tree representing, first, arboricultural management of the trees which comprise it and, second, an ecological, systems based approach which values the ecosystem services these trees provide.

Management of any resource depends on the managers of that resource having sufficient information to make knowledgeable decisions. This need for information applies to urban trees and the street tree inventory has been the primary vehicle for urban forest managers to obtain the information they need to manage the urban forest. A street tree inventory is a survey of publicly managed trees in a community or municipality. In a typical inventory, data is collected about each tree including genus, species, trunk diameter, condition, management needs, and, if applicable, street address location. Inventories are usually conducted in one of three geographic scales. A complete inventory or census collects data for all publicly managed trees in the community. Sample and partial inventories collect data for a portion of the street tree population. In a sample inventory, the inventoried portion is randomly selected whereas in a partial inventory a particular neighborhood or area is targeted. Historically, the main reasons for conducting an inventory have been rooted in arboriculture: tree maintenance and limiting exposure to liability claims attributed to poor tree condition (Tate 1985; Bond & Buchanan 2006). Maintenance and liability concerns remain important considerations for conducting an inventory, but the inventory is also increasingly viewed as a proactive, ecological, systems based planning tool for improving urban forest health and sustainability by augmenting species diversity in a long-term planting plan (Peper et al 2004).

Advances in computers and information technology have transformed urban forest management and planning. Digitization of records once kept on paper has facilitated the rapid analysis of inventory data in computer spreadsheet programs. GIS (Geographic Information Systems) and GPS (Global Positioning System) have enabled the mapping of individual trees from longitude and latitude coordinates collected as part of the inventory process. Finally, remote sensing has made possible the analysis of urban forest canopy cover from aerial imagery. Canopy cover has proved a useful metric for assessing urban forests since moderate resolution datasets such as the National Land Cover Database are available nationwide, capture most trees located in an urban area including trees on private property that are not publicly managed, and span civil jurisdictional boundaries to link urban trees between communities and to the rural and uncultivated forests beyond them. More recently, higher resolution datasets including LIDAR data have facilitated more precise analyses of canopy cover on a community by community basis including prioritizing planting spaces for meeting canopy cover goals. While canopy cover has been used effectively to measure changes to urban forests over time, assess ecosystem benefits provided by urban trees, and set goals and priorities for urban forest planning, it does not contain the more discrete kinds of data contained in a street tree inventory such as tree species composition, relative age distribution measured by trunk diameter at breast height (DBH), and tree condition. These kinds of data are required for more detail dependent urban forest management such as evaluating species diversity, planning for invasive pests, assessing the number of new plantings necessary to sustain or increase the number of publicly managed trees, and making specific decisions as to which tree species to plant at which sites.

Ideally, an urban forestry manager would have access to both street tree inventory and canopy cover data. In reality, because street tree inventories are expensive and time consuming to conduct, most municipalities in a state and nationwide have not conducted them. The absence of a street tree inventory is particularly common for those municipalities lacking a dedicated urban forestry professional responsible for managing public trees, which is in turn often correlated with smaller sized municipalities with more modest financial resources (Maco & McPherson 2003). Therefore, while the larger cities in a state often, although not always, possess a street tree inventory, most municipalities in a state, and particularly municipalities other than the state's larger cities, do not possess a street tree inventory (Green et al 1998). This patchwork of tree inventory data existing at the statewide level has posed problems for state and federal officials involved in urban forest management and planning. For example, it is difficult for officials to gauge the statewide impact of an invasive pest species such as the Emerald Ash Borer (EAB) on publicly managed street trees when most municipalities in the state do not have street tree inventories. They can only guess at the number of publicly managed ash trees at risk to the EAB and whose removal may need to be planned and budgeted for.

Attempts have been made to "see the forest" of publicly managed trees at the statewide level by assembling street tree inventory data for municipalities in a state possessing street tree inventories. In Indiana, a Sample Urban Statewide Inventory (SUSI) study comprised of street tree inventory data from twenty-three municipalities was commissioned in 2008 (Louks 2010); the study evaluated data from these municipalities and derived estimates of tree species composition (Davey Resource Group 2010A) and environmental services and economic benefits provided by street trees (Davey Resource Group 2010B) for 567 Indiana communities. In California, Lesser (1996) analyzed street tree inventory data from twenty-one Southern California cities and concluded that species diversity was declining and that more small statured trees were being planted than large statured trees, particularly in coastal communities. In New Jersey, data collected statewide from 432 plots (i.e. four one quarter mile long plots in 108 communities) in 1994 and 1999 found a lack of diversity in street tree plantings with a preponderance of maples (NJ Forest Service 2000). In Virginia, street tree inventory data from eight municipalities has been used to assess the potential impact of ash tree loss due to the EAB on the state's street tree population and the ecosystem services provided (Wiseman & Wright 2010). In South Dakota, thirty-four municipalities were surveyed for genus and species composition of their street trees and susceptibility to ash tree loss due to the EAB (Ball et al 2007). Additional efforts have included estimates of street tree species composition and street tree numbers statewide based on questionnaires in California (Bernhardt & Swiecki 1993, Thompson 2006) and Ohio (Sydnor et al 2007) and on sampled roadside plots in Maryland and Massachusetts (Cummings et al 2004). On a broader geographic scale, Raupp et al (2006) evaluated street tree vulnerability to the EAB and the Asian Longhorned Beetle (ALB) in the Eastern United States and Canada from street tree inventory data collated from twelve municipalities and one college campus, and McPherson and Rowntree (1989) used street tree inventory data from twenty-two municipalities distributed nationwide to study stocking levels, trees per capita, and the trend towards planting small sized trees as opposed to large sized ones.

The most reliably accurate analysis of publicly managed trees at the statewide level would be a census or complete count of all publicly managed trees in all municipalities in a state. For many reasons, including as mentioned the fact that most municipalities in a state, and especially municipalities other than a state's larger cities, lack a street tree inventory, such a census is not realistically achievable. Accordingly, any analysis of publicly managed trees at the statewide level must be based on a portion or sample of trees. Accuracy of such an analysis will in turn depend but not be limited to such factors as the number of trees in the sample, their geographic distribution, and the acceptable range of error. In the studies listed above, these factors vary widely. For example, in the Maryland and Massachusetts study (Cummings et al 2004), 286 randomly selected roadside plots containing 883 trees were sampled in Massachusetts and 296 randomly selected roadside plots containing 1,124 trees were sampled in Maryland. In the South Dakota study (Ball et al 2007), records for 22,390 trees were collected from a sample of municipalities stratified by population class and location east or west of the Missouri River. In the California study (Lesser 1996), results were generated from 370,000 tree records assembled from twenty-one Southern California municipalities stratified into coastal and inland groups.

Analyses of rural, uncultivated forests are routinely made on a statewide level. For example, the United States Forest Service's Forest Inventory and Analysis (FIA) program estimates the number of trees and species and genus composition on both a statewide and regional basis. These estimates are derived from data collected from two sources: first, 4.5 million remote sensing plots interpreted from aerial imagery and, second, 125,000 permanent field plots containing 1.5 million trees (USDA Forest Service 2001). Variables for which data are collected include tree and sapling data (tree species, diameter at breast height, decay class, and damage type), regeneration data (tree species and seedling count), plot level data (size of forested area, water proximity, trails or roads, recreation use, land use impact), and condition class data (slope, aspect, litter and humus depth, land cover type, and soil type, texture, and erosion class) (USDA Forest Service 1998). These analyses have been used to analyze historical trends in tree species composition, number of trees, and stand density. Data from the FIA program have also been combined with environmental variables such as mean January temperature, annual precipitation, soil bulk density, and soil pH to predict future trends in tree species composition due to climate change (USDA Forest Service 2007). Whether these analyses focus on the future or the past, rural uncultivated forests differ from urban forests in one fundamental way: rural uncultivated forests are largely, although not exclusively, the product of naturally occurring, landscape scale ecological processes, but urban forests, and especially publicly managed street trees, are largely the product of human intervention. In other words, many of the variables and factors that explain the characteristics of rural uncultivated forests will not necessarily explain the characteristics of urban cultivated forests, especially at a statewide or regional level. Nevertheless, the systematic and comprehensive coverage of FIA field data – there are 12,815 FIA field plots alone in New York State, for example (USDA Forest Service 2010a) – provides a breadth and depth of understanding for a state's rural uncultivated forests not yet achieved for a state's urban cultivated forests and, in particular, its publicly managed street trees despite attempts to do so.

It is the premise of this research that, if a sufficient number of street tree inventories can be obtained from municipalities in a state possessing an inventory, then data assembled from these inventories will enable urban forest managers and planners to "see the forest" of publicly managed trees at the statewide level with greater accuracy than has so far been attainable. The number of inventories deemed sufficient will be proportional to the number of municipalities in a state and therefore vary by state; states with a larger number of municipalities will require more inventories and states with a smaller number of municipalities will require fewer inventories. A broad geographic distribution of inventories will also be required to account for variability in tree populations based at least in part on environmental factors such as minimum winter temperatures and plant hardiness. Finally, data formatting must be standardized between inventory datasets. Since there has been no standardized methodology or format for collecting street tree inventory data, the presence or absence of data fields often differs from one inventory to the next and measures for the same data fields can differ widely also. For example, trunk diameter can be measured at breast height (DBH) at approximately 4½ feet above the ground or by caliper at approximately 6 inches above the ground, and collected as a specific measure or within a class range (e.g. 0 to 6 inches, 6 to 12 inches, etc.); tree condition can vary from good, fair, poor, and dead (four classifications) to excellent, good, fair, poor, very poor, and dead (six classifications), all subject to interpretation; and overhead wires cited for possible conflicts with street trees may include only single and triple phase utility wires or telephone, cable, and secondary wires as well.

Notwithstanding these requirements and difficulties, the potential benefit of assembling street tree inventory data from multiple municipalities in order to create what would be in effect a statewide inventory of publicly managed trees was recognized by Washington State in March 2008 with passage of the Evergreen Communities Act. Finding that “about twelve percent of Washington's cities have urban forest management plans” and that the state needed to assist “cities, towns, and counties” in establishing “clear goals and standards for their urban forests,” the ECA envisioned assembling a statewide inventory from existing municipal inventories supplemented with additional inventories to be conducted (State of Washington 2008). The statewide inventory would then be paired with remotely sensed canopy cover assessments to provide accurate information about “the condition, structure (species composition), and function of the urban forest” statewide (Washington State DNR 2009). Unfortunately, the economic downturn in 2008 following passage of the ECA precipitated budget cuts which have precluded as of this writing implementation of the plan for a statewide inventory (Mead 2010).

Washington State is not alone in wanting a statewide inventory of its publicly managed trees. New York State has cited the creation of a “statewide database of community tree inventories” as a goal in a five year plan “to support municipalities, volunteer groups, and professional organizations in the planning and management of urban and community forests in the state” (New

York State 2010). Whether or not this goal will be achieved has yet to be determined. However, due in part to an Urban and Community Forestry program that has funded street tree inventories statewide for many years, and also to Cornell University's Student Weekend Arborist Team (SWAT) which has conducted forty street tree inventories in communities throughout New York State between 2002 and 2010, New York State possesses numerous inventories for inclusion in such a database. This research was originally conceived because of the existence of these numerous inventories coupled with the premise that, if these inventories were assembled and analyzed, they might prove sufficiently numerous and broadly distributed geographically to facilitate an accurate understanding of the structure, functions, and trends of publicly managed street trees in New York State.

Accordingly, this research has undertaken the following:

- Obtained data from street tree inventories (complete, sample, and partial) from municipalities (cities, villages, and Census Designated Places) throughout New York State

- Conducted additional inventories where needed to improve the geographic breadth of street tree data

- Created a sample of the state's population of publicly managed street trees from all assembled street tree inventory data and assessed sample validity

- Calculated summary statistics from sample data including prevalent street tree species and genera, street tree numbers per street length, and street tree benefits per tree

- Explored correlations between sample data statistics and environmental and social variables that might explain variability in New York State's street tree population

- Generated initial statistical estimates for street tree numbers statewide of prevalent street tree species and genera and statewide benefits provided by street trees

- Identified statewide trends in the planning and management of street tree populations

- Conducted a number of street tree inventories subsequent to generating initial statistical estimates and compared statistics from these inventories with the initial statistical estimates and statewide trends in the planning and management of street tree populations

- Updated initial estimates with test inventory statistics to generate final statewide estimates for street tree numbers statewide of prevalent street tree species and genera and statewide benefits provided by street trees

- Made recommendations on the basis of final statewide estimates and trends identified for the future planning and management of street tree populations in New York State

- Evaluated whether the methodology employed in this research can be replicated by other states to be used in the planning and management of street tree populations beyond New York State

Finally, the adage “You can’t manage what you don’t know” is frequently stated as a reason for individual municipalities to inventory their street trees. This research has been undertaken in that vein although at a much more extensive scale. It is hoped that the statistics and estimates contained in this research will enable state officials to “see the forest” of publicly managed trees at the statewide level and will facilitate improved planning and management of these trees on a statewide basis. Given the current challenge posed to tree health by invasive pest species and the future challenge likely to be posed by climate change, broad scale planning and management are needed to protect the investments made in publicly managed trees and to preserve the benefits they provide to community residents. Moreover, since these challenges, investments, and benefits are not unique to New York State, but are shared throughout the United States, it is important to know whether the methodology employed in this research can be replicated by other states to “see the forest” of publicly managed trees in those states as well.

CHAPTER 2

INVENTORY DATA AND SAMPLE VALIDITY

New York State is the thirtieth largest state in the United States with a land area of 47,214 square miles; it is also the third most populous state with an estimated population of 19,378,102 in 2010 and the seventh most densely populated state with a population of 410.4 per square mile of land area (US Census Bureau 2011). The state is divided into 62 counties which are subdivided further into 932 towns. At the time of initial writing between 2010 and 2011, it also contained 62 cities and 556 villages incorporated under state law with defined boundaries as well as 435 Census Designated Places (CDPs), unincorporated concentrations of population with defined boundaries identified by a name (NYS GIS Clearinghouse 2010). Results from the 2010 United States Census indicated that the number of cities remained at 62, the number of villages had decreased by one to 555, and the number of CDPs had increased to 572 (US Census Bureau 2011). For reasons that will become clear in later chapters, change in the number of cities, villages, and CDPs can impact the statistical estimates of this research. Since change in these entities is constant, this research has been designed to accommodate it. An analysis will be made in a subsequent chapter with respect to the impact of change in the number of cities, villages, and CDPs and in additional metrics associated with this research on statistical estimates. However, in this chapter, the methods and analyses described are based on metrics collected in 2010 prior to the release of results from the 2010 United States Census.

Between 2008 and 2010, 586 New York State cities and villages, or 94.82% of all villages and cities in the state at that time, were contacted by e-mail or telephone and asked about the presence or absence of an inventory of community trees. Cities and villages were prioritized rather than counties, towns, and CDPs based in part on surveys conducted in 2004 and 2009 by the New York State Urban & Community Forestry Council (NYSUCFC), a volunteer group organized in 1999 to advise and assist the New York State Department of Conservation (DEC) in executing its Urban and Community Forestry policies. These surveys indicate that New York State cities are more likely to have a street tree inventory than villages, and towns are much less likely to have an inventory than villages or cities (Table 2.1).

Table 2.1 2004 and 2009 New York State Urban & Community Forestry Council (NYSUCFC) Surveys

Municipality Type	Respondents 2004 + 2009	Respondents per Muni Type	Respondents w/Inventories	Respondents w/Inventories per Muni Type
City (*n*=62)	40	64.52%	42.50%	27.42%
Village (*n*=556)	229	41.19%	29.26%	12.05%
Town (*n*=932)	127	13.63%	5.51%	0.75%

Initial results from seeking inventories from cities and villages in New York State indicated a lack of inventories for municipalities with populations between 20,000 and 80,000. In summer 2008, sample windshield surveys were conducted in six upstate New York State cities (Auburn, Binghamton, Corning, Elmira, Geneva, Utica) according to a stratified land use methodology described in Jaenson et al (1992); tree species and DBH (trunk diameter at breast height) data were collected. Subsequent results indicated a lack of inventories for municipalities in northeastern New York State. In summer 2010, complete windshield surveys were conducted in seven New York State villages (Champlain, Chateaugay, Heuvelton, Keeseville, Port Henry, Rouses Point, and Waddington); data for tree species alone was collected.

Inventories were obtained from most, but not all municipalities responding affirmatively to possessing one. Some municipalities that responded affirmatively were unable to locate their inventory and one municipality refused to provide its data. Other municipalities possessed paper-based inventories which were at least fifteen years old; a judgment was made that these inventories were too out-of-date for their data to be reliably accurate and these municipalities were not asked to provide them. In addition to the street tree inventories obtained from cities and villages, inventories were obtained from thirteen CDPs and two towns. The town inventories are partial inventories conducted for significant portions of those towns. Most of the CDP inventories are inventories conducted for two other towns where data has been apportioned to CDPs contained within town boundaries. Table 2.2 shows the breakdown of municipalities for which street tree inventory data have been obtained in New York State.

Table 2.2 Breakdown of municipalities for which street tree inventory data have been obtained in New York State

Municipality Type	Number of Inventories	Municipality Type Statewide	Percentage of Statewide Municipality Type
City	26	62	41.94%
Village	97	556	17.47%
Town	2	932	0.21%
CDP	13	435	2.99%

With respect to cities and villages, the distribution of inventories obtained is consistent with the distribution of inventories in the 2004 and 2009 NYSUCFC surveys, namely that street tree inventories are more likely to be found and data obtained for cities than villages. This distribution parallels statistics from the Community Accomplishment Reporting System (CARS) of the USDA Forest Service's Urban and Community Forestry Program. CARS requires states to collect annually urban and community forestry data from municipalities about professional staff, tree protection ordinances or policies, advisory committees, and active urban forest management plans (USDA Forest Service 2010b). The assumption is made that an active urban forest management plan is based on and indicates the existence of a street tree inventory or assessment although inventory type (complete, partial, or sample) may vary and the assessment may include canopy cover analysis from aerial imagery (Parry 2009). The 2009 CARS statistics indicate that 35 of 62 New York State cities, or 56%, and 114 of 556 New York State villages, or 21% possess active management plans assumed to be based on a street tree inventory or assessment; no management plans or assessments were found for New York State CDPs and CARS does not collect data for towns (USDA Forest Service 2010c).

Therefore, street tree inventory data was obtained from 136 of 1053 cities, villages, and CDPs (12.92%) and portions of two towns in New York State. Figure 2.1 shows the location of these inventories in New York State. This data comprises a sample of New York State's population of publicly managed street trees. Validity of this sample must be assessed. At face value, a sample comprising 12.92% of New York State cities, villages, and CDPs might

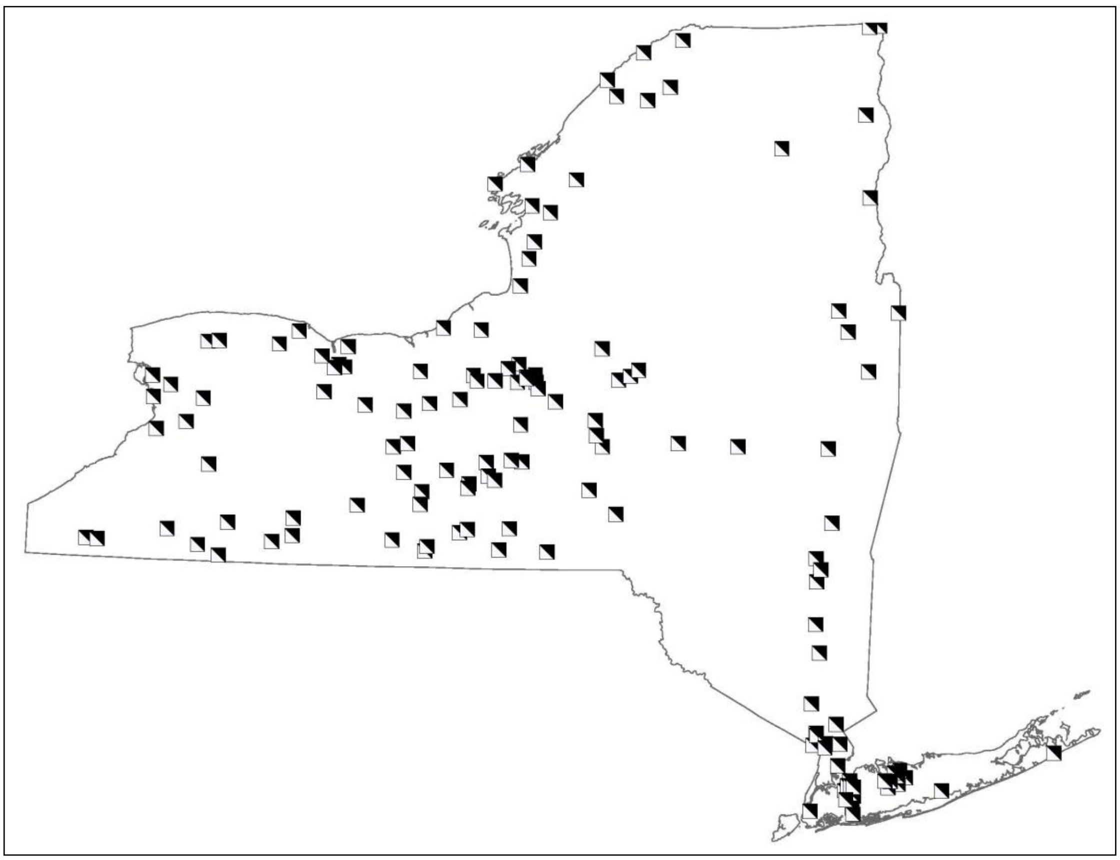


Figure 2.1 Municipalities in New York State where street tree inventory data has been obtained

be considered sufficient to “see the forest” of publicly managed trees in New York State, although it is evident from Table 2.2 that cities are better represented percentagewise in this sample than other municipality types such as villages and geographic and demographic differences do exist between cities and villages statewide. For example, in the 2000 US Census, the median population for New York State cities was 20,650 while the median population for New York State villages was 1,757; the mean land area for New York State cities was 11.39 square miles while the mean land area for New York State villages was 1.77 square miles; and the mean population per square mile for New York State cities was 5123.47 while the mean population per square mile for New York State villages was 2187.15 (US Census Bureau 2010a). These differences may not significantly impact street tree inventory data or bias the data sample obtained. In fact, preliminary analyses associated with this research found that municipality type, population size, and population density had little explanatory power for street tree population characteristics such as species diversity and genus or species composition. These issues will be discussed in greater detail in subsequent chapters.

While municipality type, population size, and population density may not be helpful in assessing the validity of the data sample obtained, land area should be considered, especially with regard to estimating street tree numbers. Municipalities with larger land area can be expected generally to contain more street segments and street length than municipalities with less land area. Since street trees are a function of streets – i.e. without streets there would be no street trees – it is fair to assume that street trees will increase in number as the number of street segments and amount of street length increase. Therefore, assessing the validity of the data sample should consider not simply the number of municipalities from which inventories have been obtained, but the area of those municipalities and, more specifically, the number of street segments and the amount of street length contained in these municipalities.

The number of all street segments contained within and intersecting municipal boundaries can be delineated easily using GIS (Geographic Information Systems) software. Length of these street segments can likewise be easily summed. However, these measures of street segments and street length may not be sufficiently valid for the purposes of this study since not all street segment types are equally likely to contain street trees. For example, primary and secondary roads with underpasses and interstate highways are street types where street trees are unlikely to be found. Consequently, a methodology to differentiate those street types where street trees would be expected to be found from those street types where street trees would not be expected to be found would increase accuracy of any estimates of street tree numbers based on measures of street segment numbers and street length. Such a methodology has been defined in a street segment sampling strategy devised by the USDA Forest Service (2008a) for i-Tree STRATUM software that has been updated for i-Tree Streets software (USDA Forest Service 2010d). In this sampling strategy, streets are differentiated by classes defined by the United States Census Bureau in TIGER/Line (Topologically Integrated Geographic Encoding and Referencing system) street centerline GIS shapefiles. Street types classified as “primary road without limited access, US highways, unseparated," "secondary and connecting road, state highways, unseparated," and "local, neighborhood, and rural road, city street, unseparated" would be expected to contain street trees. Street types classified as "primary road with limited access or interstate highway, unseparated," "secondary and connecting road, state highways, unseparated, in tunnel," and "local, neighborhood, and rural road, city street, unseparated, underpassing" would not be expected to contain street trees.

Differentiating street types where street trees would be expected to be found from street types where street trees would not be expected to be found pursuant to i-Tree software's street segment sampling strategy provides a first step in constructing a measure to assess sample validity of street tree inventory data obtained. This measure will compare street length for street types expected to contain street trees for municipalities where street tree inventory data has been obtained with street length for street types expected to contain street trees for all municipalities statewide. Figure 2.2 illustrates a methodology for selecting street types expected to contain street trees. This methodology follows i-Tree software's street segment sampling strategy, but TIGER/Line codes have been adapted for use with New York State ALIS (Accident Location Information System) street centerline files obtained from the New York State GIS Clearinghouse. ALIS files have been selected instead of the TIGER/Line files because such "local" files are updated more regularly and have been found to be more accurate than TIGER/Line files (Zandbergen et al 2011). In addition, streets described in the ALIS files as driveways, parking lots, and "unnamed streets" (e.g. service roads, roads in shopping malls) have been deleted to increase estimate accuracy still further.

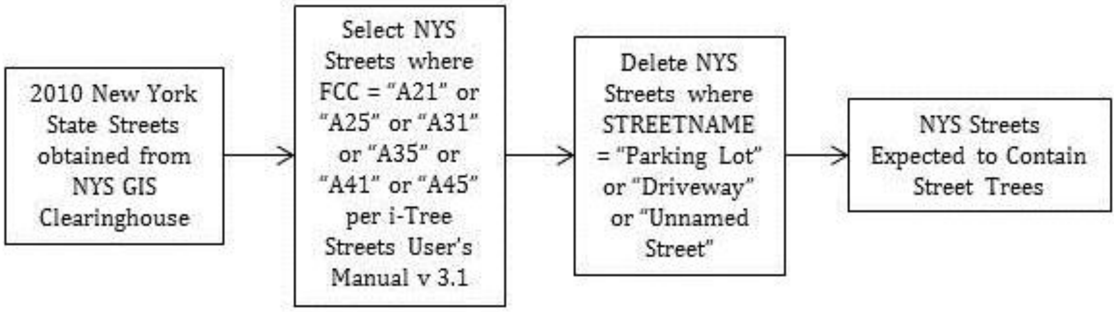


Figure 2.2 Methodology for selecting New York State streets expected to contain street trees

The methodology illustrated in Figure 2.2 does not select streets into municipalities. Accordingly, the first step must be followed by a second as illustrated in Figure 2.3 in which two subsets are derived: (1) "NYS Streets Expected to Contain Street Trees for Municipalities where Street Tree Data has been Obtained" and (2) "NYS Streets Expected to Contain Street Trees for all NYS Census Places." These subsets are produced from a methodology illustrated in Figure 2.3 whereby boundaries from New York State Census Places (i.e. all cities, villages, and CDPs), are used to select street segments contained within or touching municipal boundaries; boundaries for municipalities where street tree inventory data has been obtained are differentiated from boundaries for all municipalities and used to select street segments for these municipalities. Street length is then summed for all street segments contained in these subsets.

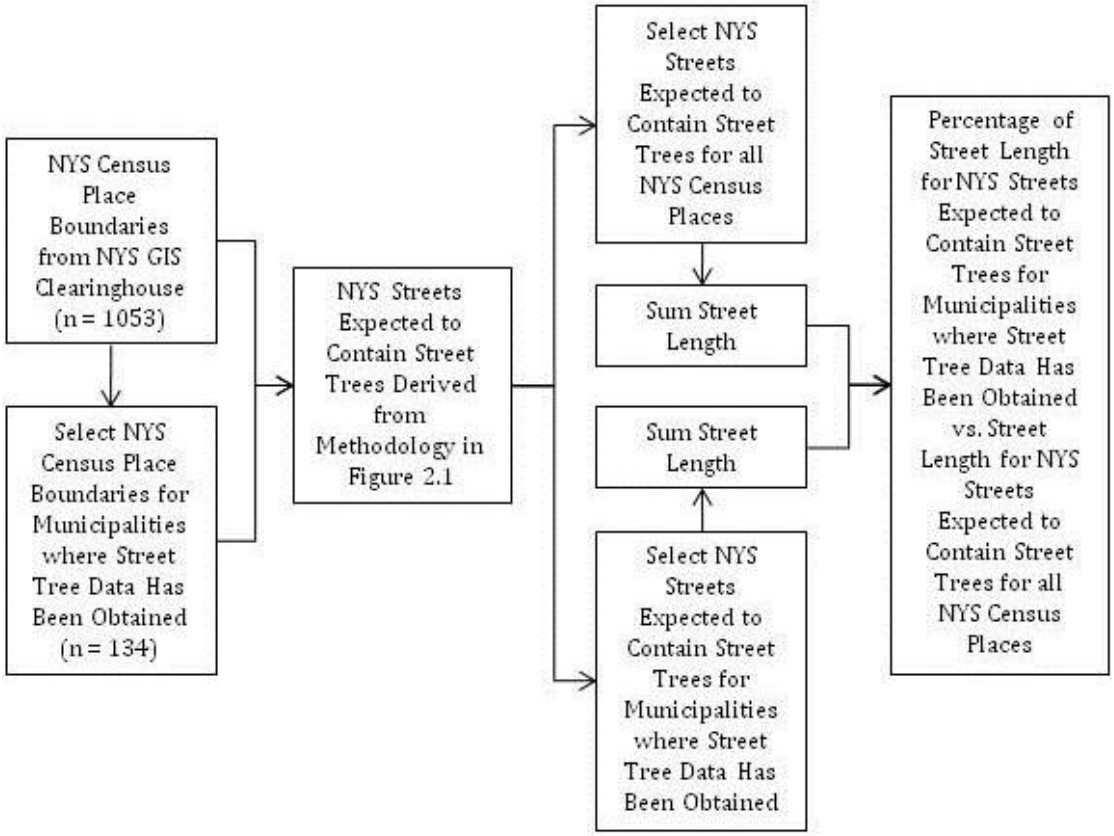


Figure 2.3 Methodology for comparing street length for NYS streets expected to contain street trees for municipalities where street tree inventory data has been obtained with street length for NYS streets expected to contain street trees for all Census Places (cities, villages, and CDPs) in New York State

Results comparing these subsets are as follows: street length for NYS streets expected to contain street trees for all Census Places (cities, villages, and CDPs) in New York State is 65,134,633 meters; street length for NYS streets expected to contain street trees for municipalities where street tree inventory data has been obtained is 21,217,451 meters. Therefore, the percentage of street length for NYS streets expected to contain street trees for municipalities where street tree data has been obtained is approximately 32.57% of street length for NYS streets expected to contain street trees for all Census Places statewide. At face value, this would appear to comprise an adequate sample, especially since for the USDA Forest Service i-Tree street segment sampling strategy where a 10% standard error is acceptable, a 3-6% sample of total street segments is deemed adequate (USDA Forest Service 2008b). However, consideration should also be given to the geographic distribution of street length and, in particular, to the relationship between street length and minimum winter temperatures affecting plant hardiness. It was hypothesized early on in this research that geographic variability in New York State street trees would be explained at least in part by winter minimum temperature and plant hardiness. This hypothesis was based in part on horticultural reference books such as Dirr (1998) which judge plant hardiness to be a limiting factory in the landscape use of woody plants. Mean January temperature has also been employed as a predictor variable in the United States Forest Service's Random Forest (RF) Model assessing the current and future status following climate change of 134 tree species in the eastern United States (USDA Forest Service 2007). Finally, winter minimum temperature and plant hardiness have figured in previous analyses of street trees on a regional basis such as Lesser's research in Southern California (1996) where street trees in coastal cities where differentiated from street trees in inland cities, in part because the coastal cities experience very mild winters and the inland cities experience occasional winter frosts.

Since, as stated above, street trees are a function of streets and preliminary analyses associated with this research indicated that geographic variability in the species and genus composition of street trees in New York State could be explained at least in part by minimum winter temperatures affecting plant hardiness, assessment of sample validity and, in particular, the relationship between municipalities where street tree inventory data has been obtained and street length for streets expected to contain street trees should consider not simply summed street length for those municipalities, but the relationship of summed street length to minimum temperatures affecting plant hardiness. Consideration of this relationship is complicated by the fact that measurement of minimum winter temperatures is a complex endeavor made more so by recent evidence of climate change. Additionally, measurement of minimum winter temperatures should be broadly available and replicable by other states to facilitate conducting statewide street tree assessments in those states.

Horticultural reference books such as Dirr (1998) commonly attribute their plant hardiness ratings to the United States Department of Agriculture (USDA) Plant Hardiness Zone Map (US National Arboretum 1990) which plots zones of average annual minimum temperatures for the United States. Each zone is based on a 10^{o} Fahrenheit increment (e.g. Zone 5: -20 to -10^{o}F, Zone 6: -10 to 0^{o}F) and each zone is divided into *a* and *b* zones with lower temperatures in the *a* zone (e.g. Zone5*a*: -20 to -15^{o}F, Zone 5*b*: -15 to -10^{o}F). There are five 1990 USDA Plant Hardiness Zones for New York State: Zones 3, 4, 5, 6, and 7 (Figure 2.4). The USDA decided subsequently to update the 1990 map and a new version depicting changes to 1990 zone boundaries (i.e. a northward movement of zone boundaries reflecting warmer minimum temperatures) was drafted in 2003 by the American Horticultural Society, but was rejected by the USDA on methodological grounds. A new version of the map is expected to be released in 2012.

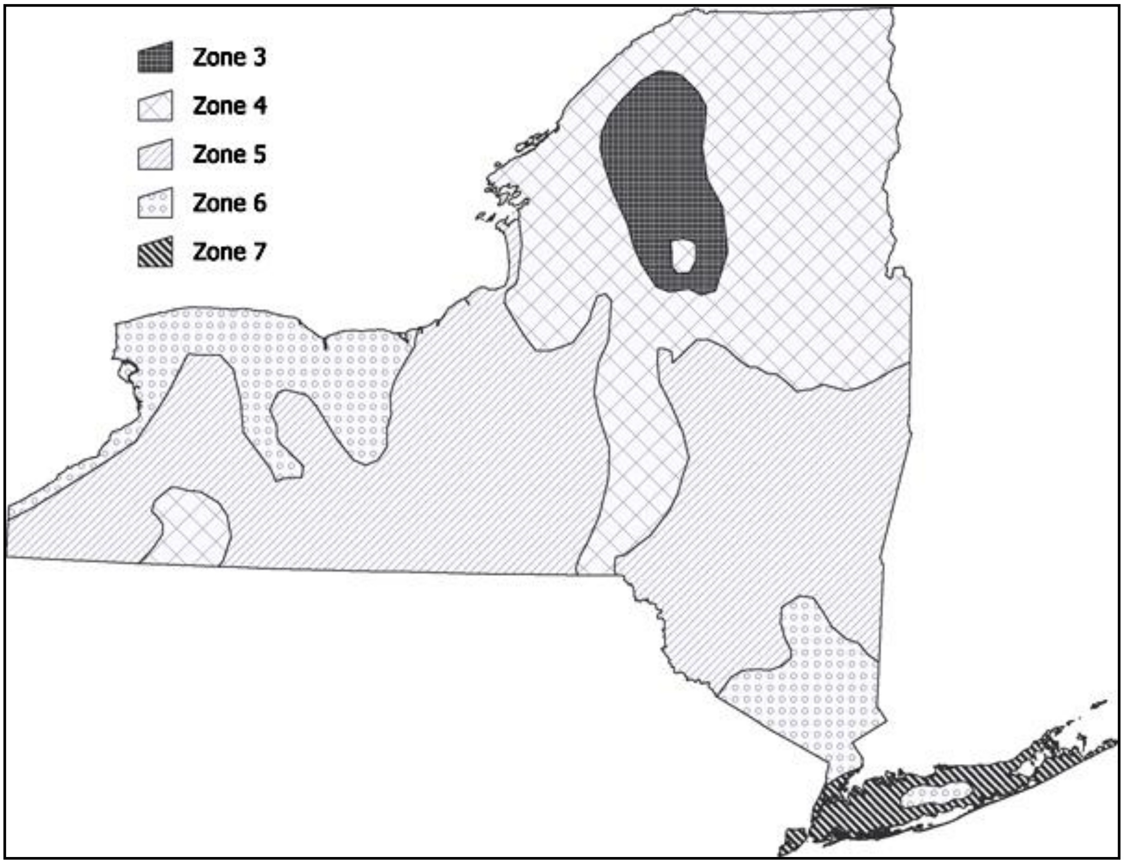


Figure 2.4 1990 USDA Plant Hardiness Zones for New York State

The USDA Plant Hardiness Zone Map is one example in which minimum winter temperatures have been plotted. The Sunset Publishing Corporation, which publishes Sunset Magazine and Sunset Western Gardener, has created a national map of United States climate zones accounting not only for “winter lows,” but also for distance from the equator, elevation, ocean influence, continental air mass influence, mountains and hills, and local terrain (2011). Because the Sunset climate zones are based on many factors besides minimum winter temperatures, they will not be considered further in this discussion. The PRISM (Parameter-elevation Regressions on Independent

Slopes Model) Climate Group, Oregon State University (2007) has mapped areas of minimum temperature range from thirty year normals (i.e. the arithmetic mean of values over thirty years) used by the National Climatic Data Center (NCDC) to measure climate data (Figure 2.5). Finally, the Northeast Regional Climate Center (2011) has plotted areas of minimum monthly and annual temperatures from thirty year normals for states in the northeastern United States, including New York State (Figure 2.6).

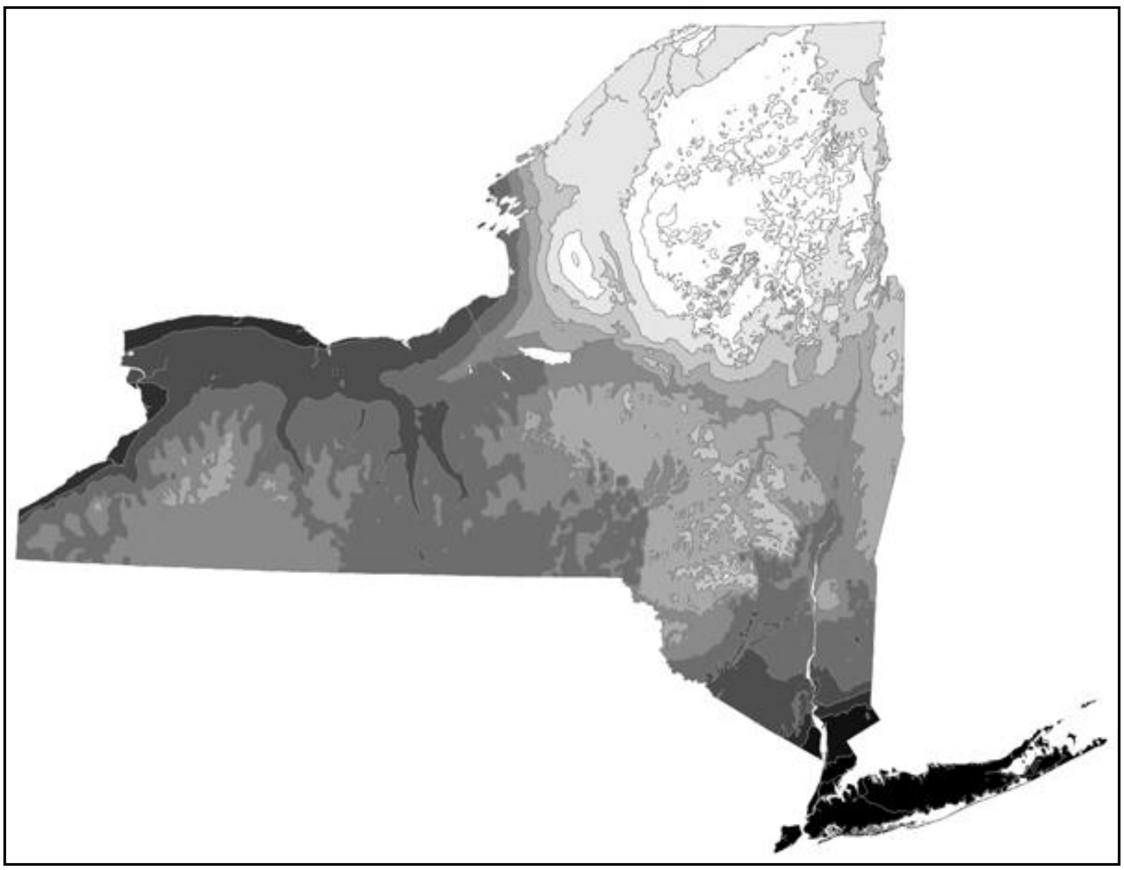


Figure 2.5 Areas of minimum temperature range mapped by PRISM

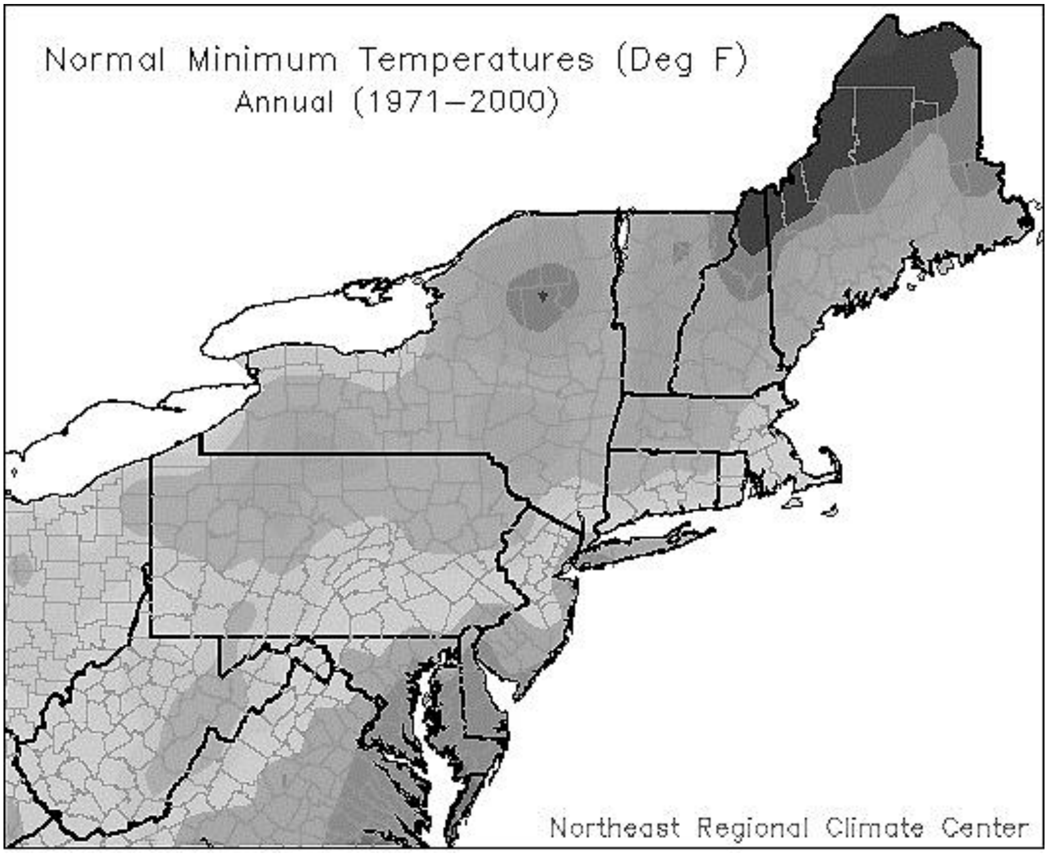


Figure 2.6 Areas of minimum temperature range mapped by the Northeast Regional Climate Center

The PRISM map looks to offer the most precision as 14 zones are mapped in New York State at increments of 2° Fahrenheit. The Northeast Regional Climate Center offers slightly less precision as 9 zones are mapped in New York State at increments of 2° or 3° Fahrenheit. The 1990 USDA Plant Hardiness Zone offers the least precision as 5 zones are mapped in New York State at increments of 10° Fahrenheit. However, while precision of a measure can be an important factor in evaluating accuracy and sample validity, there are additional factors that must be considered such as sample size.

The sample of New York State street tree inventory data is comprised of data assembled from 138 municipalities. This is not a large sample, especially if the municipalities and their data (street tree and street length) are associated with and aggregated by minimum winter temperature range. Since greater sample size tends to produce a sample mean more closely approximating the population mean, and a sample size of $n \geq 30$ is a common threshold to apply the Central Limit Theorem, it is likely to be statistically more advantageous to aggregate data to fewer groups such as those plotted by the 1990 USDA Plant Hardiness Zone Map than to more groups such as those plotted by PRISM and the Northeast Regional Climate Center. In addition, the 1990 USDA Plant Hardiness Zone Map is national in scope, more broadly available, and more widely used than the other data and therefore appears to facilitate more readily research replicability in other states. Based as well on the expectation that an updated version of the 1990 USDA Plant Hardiness Zone Map will be issued in 2012, a decision was made to use the 1990 USDA Plant Hardiness Zone Map to assess sample validity and especially the relationship between street tree inventory data, street length for streets expected to contain street trees, and minimum temperatures affecting plant hardiness

To account for the relationship in New York State between street length for streets expected to contain street trees and minimum temperatures affecting plant hardiness, New York State zone boundaries from the 1990 USDA Plant Hardiness Zone Map were digitized with GIS software. Digitizing boundaries is necessary because the 1990 USDA Plant Hardiness Zone Map was not issued in GIS shapefile format, although this will be done for the 2012 update. Streets expected to contain street trees identified by the methodology in Figure 2.2, and selected into municipalities according to the methodology in Figure 2.3, were then selected into their respective plant hardiness zones and their length summed. The methodology for selecting New York State streets expected to contain street trees into plant hardiness zones and summing their length is described in Figure 2.7. Results are contained in Table 2.3.

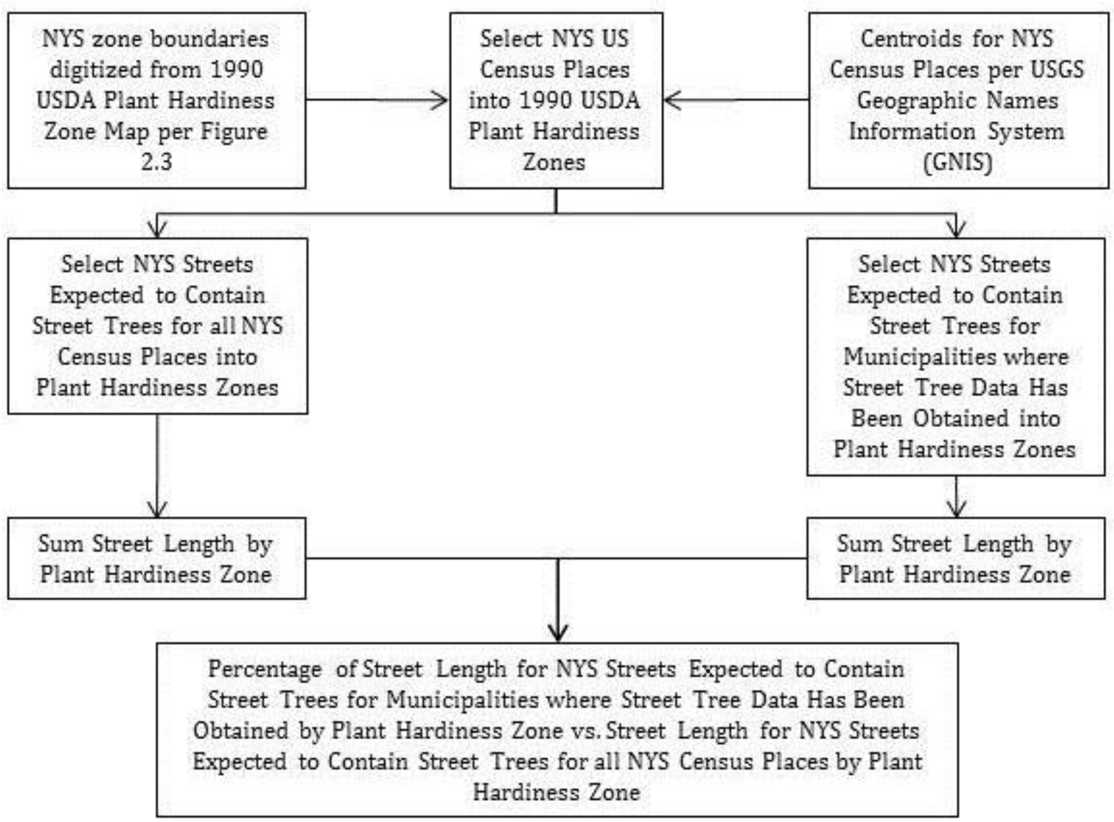


Figure 2.7 Methodology for selecting street length for NYS streets expected to contain street trees statewide and for municipalities where street tree inventory data has been obtained into their respective 1990 USDA Plant Hardiness Zones

Table 2.3 Percentage of street length (meters) by 1990 USDA Plant Hardiness Zone for municipalities where street tree inventory data has been obtained versus all NYS Census Places

	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Street Length -- NYS Municipalities With Street Tree Inventory Data	91160	1313156	4175985	3881400	11812080
Street Length -- All NYS Census Places	190874	4342440	13077273	19297512	28226563
Percent Street Length With Inventory Data	47.76%	30.24%	31.93%	20.11%	41.85%

Results shown in Table 2.3 indicate that percent street length with inventory data is less than the statewide average of 32.57% for Zones 4, 5, and 6 and greater than the statewide average of 32.57% for Zones 3 and 7. Having sufficient data for Zones 6 and 7 is a concern since 77.13% of all statewide Census Place street length for streets expected to contain street trees is contained in these densely populated zones which include Westchester, Nassau, and Suffolk Counties and New York City. A 20.11% sample for Zone 6 and a 41.85% sample for Zone 7 would appear adequate at face value.

It should be noted, however, that percentage of street length expected to contain street trees contained within Census Place boundaries varies considerably by 1990 USDA Plant Hardiness Zone. For example, in Zone 6 the percentage of street length expected to contain street trees contained within Census Place boundaries is 44.90% of all such street length found in Zone 6; in Zone 7 the percentage of street length expected to contain street trees contained within Census Place boundaries is 98.63% of all such street length found in Zone 7. By contrast, in Zone 3 the percentage of street length expected to contain street trees contained within Census Place boundaries is 5.47% of all such street length found in Zone 3; in Zone 4 the percentage of street length expected to contain street trees contained within Census Place boundaries is 11.11% of all such street length found in Zone 4; and in Zone 5 the percentage of street length expected to contain street trees contained within Census Place boundaries is 15.36% of all such street length found in Zone 5. These percentages reflect differences in population density (population per area) and in street length density (street length per area). Table 2.4 illustrates the relationship between the percentage of street length expected to contain street trees contained within Census Place boundaries and street length density.

Table 2.4 Percentage of street length (meters) expected to contain street trees contained within Census Place boundaries and street length density, by 1990 USDA Plant Hardiness Zones for New York State

	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Percent Street Length Expected to Contain Street Trees Contained Within Census Place Boundaries	5.47%	11.11%	15.36%	44.90%	98.63%
Street Length Density	0.05%	0.09%	0.15%	0.27%	0.82%

Based on the figures in Table 2.4, it is evident that a sampling methodology relying exclusively on Census Place boundaries may not account sufficiently for all publicly managed street trees in New York State since, other than Zone 7, meaningful fractions of street length expected to contain street trees are not contained within Census Place boundaries. Although much of this street length is located in areas of low population density and would not be expected to contain street trees, some of this street length is located in areas of significant population density, but is not contained within Census Place boundaries (Figure 2.8). Accordingly, a methodology is needed to account for street length expected to contain street trees for areas of significant population density not contained within Census Place boundaries.

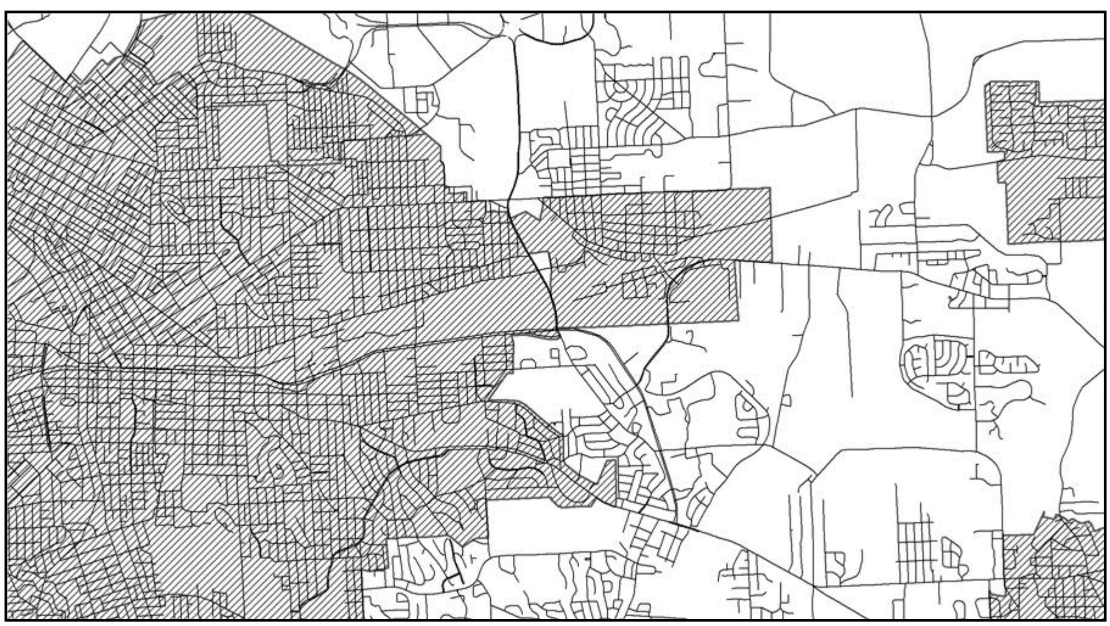


Figure 2.8 Hatched areas showing streets of types expected to contain street trees contained within Census Places (City of Syracuse, Villages of East Syracuse, Manlius, and Minoa, Onondaga County, 1990 USDA Plant Hardiness Zone 5)

Population density of at least 500 persons per square mile (ppsm) within a two and one-half mile road distance “jump” of an urban area has been one criterion used by the United States Census Bureau to recognize urban territory beyond an urban core (US Census Bureau 2010b). Census Blocks are the most discrete geographical areas used by the Census Bureau for measuring population. Since the area of each Census Block is known, population density can be calculated for Census Blocks and streets can be selected into Census Blocks because they have defined boundaries. Changing the two and one half mile “jump” to a one and one half mile “jump” has been proposed for the 2010 Census due to a perceived overextension of urban area designation. Regardless of this proposed change, the above criterion does not capture population concentrations such as hamlets (populated sections of towns not incorporated as villages) located in suburban or rural areas that may not be contained within Census Places, yet are areas where street trees can be found. Accordingly, the following methodology was employed using Census Blocks to account for street length expected to contain street trees for areas of significant population density not contained within Census Place boundaries, but located both in proximity to urban areas and in more rural areas: (1) New York State Census Blocks from the 2000 Census were obtained from the NYS GIS Clearinghouse (2) Census Blocks contained within Census Places were deleted (3) Remaining Census Blocks with population density of at least 500 ppsm were selected as a subset (4) Subsetted Census Blocks with a population density of at least 500 ppsm were associated with their respective 1990 USDA Plant Hardiness Zones similar to the methodology illustrated in Figure 2.5 (5) New York State streets expected to contain street trees identified by the methodology illustrated in Figure 2.2, were selected into subsetted Census Blocks with a population density of at least 500 ppsm and their length summed. Figure 2.9 illustrates this methodology. Figures 2.10 and 2.11 depict additional streets captured using this methodology compared to Figure 2.8, but without including roads in areas of low population density, such as rural roads. Results from the methodology illustrated in Figure 2.9 are contained in Table 2.5.

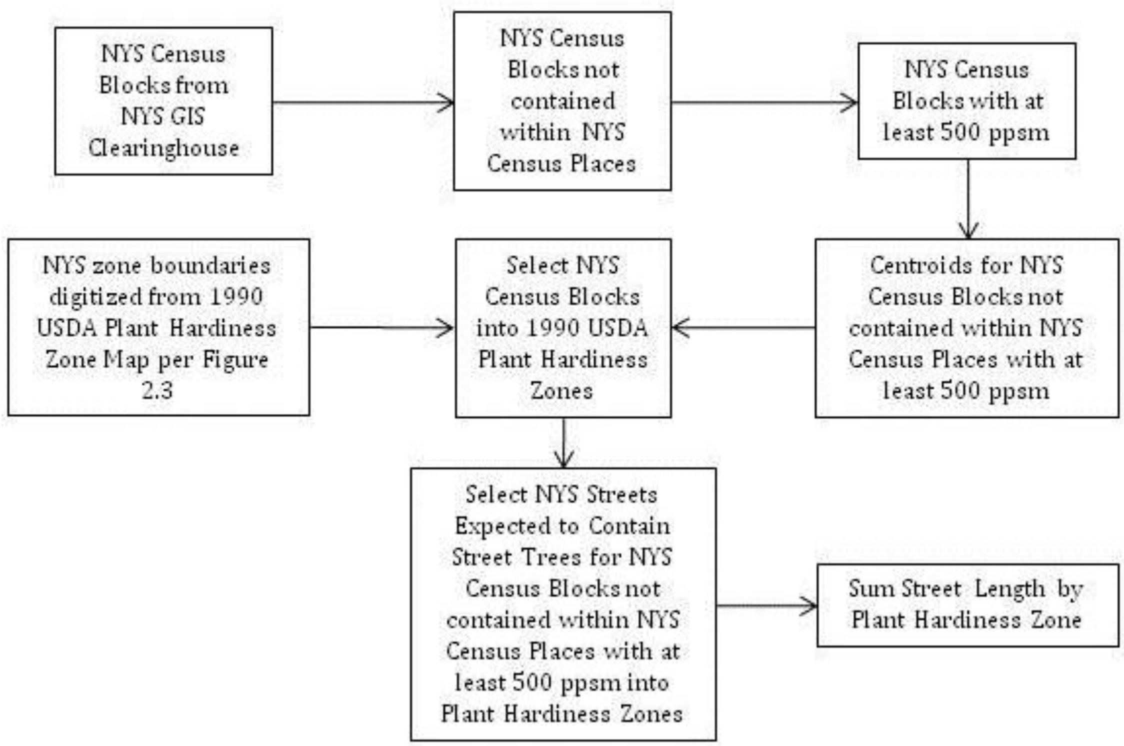


Figure 2.9 Methodology for selecting street length for NYS streets expected to contain street trees statewide for Census Blocks with at least 500 persons per square mile (ppsm) by 1990 USDA Plant Hardiness Zones

Figure 2.10 Shaded areas showing streets of types expected to contain street trees not contained within Census Places (City of Syracuse, Villages of East Syracuse, Manlius, and Minoa, Onondaga County), but which include Census Block population density of at least 500 ppsm

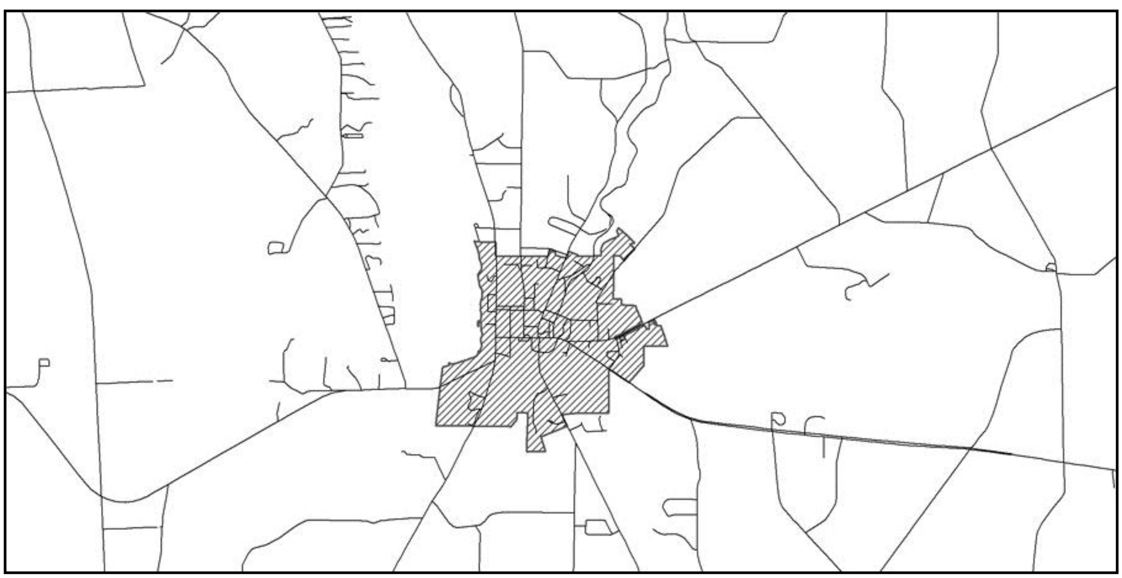


Figure 2.11 Hatched area showing streets of types expected to contain street trees contained within a Census Place: Village of Cazenovia, Onondaga County, 1990 USDA Plant Hardiness Zone 5. Rural roads in low population density areas in proximity to Cazenovia have not been selected using the methodology illustrated in Figure 2.9

Table 2.5 Street length (meters) expected to contain street trees contained within Census Blocks not within Census Places with population density at least 500 ppsm by 1990 USDA Plant Hardiness Zones for New York State

	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Street Length Expected to Contain Street Trees Within Census Blocks	132066	3006425	9203697	5847948	67749
Street Length Expected to Contain Street Trees Within Census Places	190874	4342440	13077273	19297512	28294312
Street Length Expected to Contain Street Trees Contained Within Census Blocks and Census Places	322940	7348865	22280970	25145460	28294312
Percent Increase from Street Length Expected to Contain Street Trees Within Census Places	69.19%	69.23%	70.38%	30.30%	0.24%

For 1990 USDA Plant Hardiness Zones 3, 4, 5, and 6, the methodology illustrated in Figure 2.9 and the results contained in Table 2.5 have produced significant additions of street length of streets expected to contain street trees to length contained within Census Places. Total length statewide of streets expected to contain street trees contained within Census Places and Census Blocks with a population density of at least 500 ppsm is 83,392,547 meters or 41.84% of the statewide total of 199,307,142 meters for all such street length. However, since it can be assumed that publicly managed street trees are more likely to be found in areas of greater population concentration than in areas of less population concentration, and in areas with defined boundaries rather than areas without defined boundaries, a population of streets expected to contain street trees contained within Census Places and Census Blocks with a population density of at least 500 ppsm can be expected to provide a more accurate picture of the “forest” of publicly managed street trees in New York State than would all such streets statewide.

Because Zone 3 contains 8 of 1053 Census Places located in New York State (0.76%) and only 322,940 meters of streets expected to contain street trees contained within Census Places and Census Blocks with a population density of at least 500 ppsm compared to 83,393,547 meters of such streets statewide (0.39%), and street tree species hardy in Zone 3 are not significantly different from street tree species hardy in Zone 4, street length and inventory data obtained for Zone 3 will be grouped with street length and inventory data obtained for Zone 4.

Thus, street tree inventory data obtained from 138 municipalities has been associated with street length in meters for streets expected to contain street trees contained within those municipalities and allocated to their respective 1990 USDA Plant Hardiness Zones. Summed street length in meters for streets expected to contain street trees for Census Places where street tree inventory data has been obtained allocated to 1990 USDA Plant Hardiness Zones has been delineated as a measure to assess sample validity. This measure must then be compared to the population of summed street length for all streets expected to contain street trees for all Census Places and Census Blocks not contained within Census Places with population density of at least 500 ppsm allocated similarly to 1990 USDA Plant Hardiness Zones. Table 2.6 shows the results of this comparison. Percentages range from a low of 15.44% for Zone 6 to a high of 41.75% for Zone 7. These percentages seem at face value to be adequate for sample validity. However, data collection methodologies vary considerably between the municipalities from which street tree inventory data has been obtained. Some municipalities, for example, collect data for tree genus, but not for tree species; some municipalities collect tree diameter data by the inch while others group tree diameter data within a range of inches. As a result, depending on the variable of concern, street length sample size may be reduced because of limitations of data conformity (i.e. more data may be available for tree genus than is available for tree species). Reduced street length sample size may reduce in turn predictive capacity (i.e. predictive capacity may be greater for genus composition than for species composition). These issues will be addressed in a later chapter.

Table 2.6 Comparison of summed street length (meters) of streets expected to contain street trees for Census Places in New York State where street tree inventory has been obtained with summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks not contained within Census Places with population density of at least 500 ppsm in New York State, by 1990 USDA Plant Hardiness Zones

	Zones 3 + 4	Zone 5	Zone 6	Zone 7
Street Length Expected to Contain Street Trees for Census Places With Inventory Data	1404316	4175985	3881400	11812080
Street Length Expected to Contain Street Trees Contained Within Census Places and Census Blocks	7671805	22280970	25145460	28294312
Percent Street Length Expected to Contain Street Trees for Census Places With Inventory Data vs. All Street Length Expected to Contain Street Trees Contained Within Census Places and Census Blocks	18.30%	18.74%	15.44%	41.75%
Percentage of Statewide Total	9.20%	26.72%	30.15%	33.93%

Table 2.6 additionally shows that summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places varies significantly between the four zone classes. For example, Zone 7 contains more than 3½ times (369%) the summed street length contained in Zones 3 + 4, 27% more summed street length than contained in Zone 5, and 13% more summed street length than contained in Zone 6. These differences in summed street length by zone class must be taken into account if statewide statistical analyses and estimates for publicly managed street trees are to be accurate and reliable. Accordingly, measures such as statewide summary statistics for street tree genus and species composition will be weighted by the relative percentage of summed street length contained in each zone class (i.e. Zones 3 + 4, 5, 6, and 7).

CHAPTER 3
SUMMARY STATISTICS

Street tree inventory data has been obtained from 136 of 1053 cities, villages, and CDPs (12.82%) and portions of two towns in New York State. This data has been allocated to the 1990 USDA Plant Hardiness Zone (i.e. Zones 3, 4, 5, 6, and 7) associated with the inner centroid of municipal boundaries (a centroid is the geographic center of an area and an inner centroid is a centroid located within an area's boundaries). Data from Zone 3 has been aggregated with data from Zone 4 and summary statistics generated for four zone classes (i.e. Zones 3 + 4, Zone 5, Zone 6, and Zone 7). Within Zone 7, data from New York City has been disaggregated into its five boroughs (i.e. Bronx, Brooklyn, Manhattan, Queens, and Staten Island), each of which comprises a county.

Summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places varies significantly between the four zone classes (Table 3.1). For example, Zone 7 contains more than 3½ times (369%) the summed street length contained in Zones 3 + 4, 27% more summed street length than contained in Zone 5, and 13% more summed street length than contained in Zone 6. These differences in summed street length by zone class must be accounted for if statewide statistical analyses and estimates are going to be accurate and reliable.

Table 3.1 Summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places for 1990 USDA Plant Hardiness Zone classes in New York State

	Zones 3 + 4	Zone 5	Zone 6	Zone 7
Street Length Expected to Contain Street Trees Contained Within Census Places and Census Blocks	7671805	22280970	25145460	28294312
Percentage of Statewide Total	9.20%	26.72%	30.15%	33.93%

Accordingly, measures such as statewide summary statistics for street tree genus and species composition will need to be weighted by the relative percentage of summed street length contained in each zone class. For example, to determine the relative prevalence of street tree species and genera, the mean percentages of street tree species and genera in each zone class have been weighted by the relative percentage of summed street length contained within each zone class according to the formula:

$$((w1 * m1) + (w2 * m2) + (w3 * m3) + (w4 * m4)) / (w1 + w2 + w3 + w4)$$

Where $m1$, $m2$, $m3$, and $m4$ denote the group means for each species and genus (i.e. the mean percentages for 1990 USDA Plant Hardiness Zone classes 3 + 4, 5, 6, and 7) and $w1$, $w2$, $w3$, and $w4$ denote the different weights for each group (i.e. percentages of summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places for 1990 USDA Plant Hardiness Zone classes in New York State) as stated in Table 3.1.

Genus Composition

For each municipality from which data was obtained, trees were aggregated by genus. Trees whose genus was categorized in the data as "unknown" were grouped as "Other." The sum of all trees for each genus was divided by the sum of all trees in each inventory to calculate a percentage for each genus for each inventory accurate to three decimal points. These percentages were allocated to four zone classes (e.g. Zones 3 + 4, Zone 5, Zone 6, and Zone 7) based on the 1990 USDA Plant Hardiness Zones associated with their respective municipalities. Mean and median percentage, standard deviation, standard error, and upper and lower confidence levels (UCL and LCL) were calculated (α = .10) for all genera in all zone classes.

To determine the relative prevalence of street tree genera statewide, the mean percentage of each genus in each zone class was weighted by the relative percentage of summed street length expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places within that zone class. Weighted mean percentages were ranked to determine relative prevalence statewide. Genera whose weighted mean percentage was found to be at least 1.000% were judged to be prevalent. Together these genera account for 87.075% of all trees for whom data was obtained. Table 3.2 shows statistics for the relative prevalence of street tree genera statewide.

Table 3.2 Relative prevalence of street tree genera statewide (*n* = 142)

Genus	**Zones 3 + 4 (mean %, *n* = 31)**	**Zone 5 (mean %, *n* = 60)**	**Zone 6 (mean %, *n* = 28)**	**Zone 7 (mean %, *n* = 23)**	**Weighted Mean %, All Zones**
Acer	54.774	55.880	51.080	25.830	44.135
Quercus	3.960	2.895	4.852	13.042	7.026
Platanus	0.101	0.654	3.812	13.142	5.792
Pyrus	2.245	2.423	3.302	10.359	5.364
Gleditsia	4.304	4.915	6.164	4.108	4.962
Tilia	3.551	3.234	4.472	4.559	4.086
Fraxinus	5.396	3.693	3.713	2.215	3.355
Picea	4.162	5.706	2.032	1.389	2.992
Prunus	1.342	2.198	2.509	4.048	2.841
Malus	4.490	4.277	2.304	0.659	2.474
Pinus	2.041	1.713	1.351	1.694	1.627
Ulmus	1.353	0.904	1.616	1.501	1.363
Robinia	1.271	0.822	1.123	1.130	1.058

Percentages for some street tree genera vary meaningfully between zone classes in Table 3.2. For example, *Platanus* is scarce in Zones 3 + 4 and 5, but is more common in Zones 6 and 7, presumably due to plant hardiness and minimum temperatures, and prevalence of *Acer* in Zone 7 is substantially reduced from prevalence in the other zone classes. This variation is illustrated in Figure 3.1.

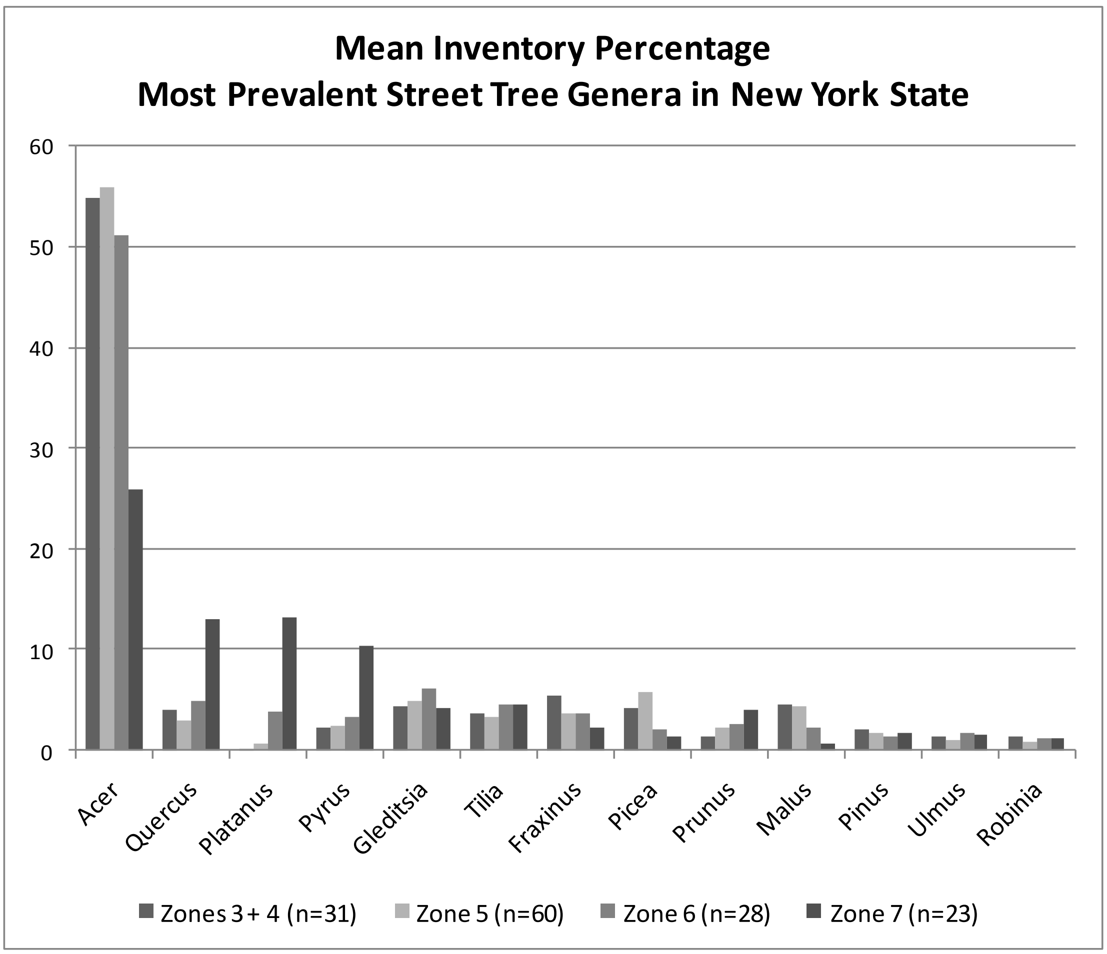


Figure 3.1 Mean inventory percentage for most prevalent street tree genera in New York State by 1990 USDA Plant Hardiness Zone class

Finally, summary statistics have been generated for prevalent street tree genera in each zone class (i.e. Zones 3 + 4, Zone 5, Zone 6, and Zone 7). These statistics can be found in Table 3.3.

Table 3.3 Summary statistics for prevalent street tree genera in New York State by 1990 USDA Plant Hardiness Zone class

Zones 3 + 4 (*n* = 31)	**Mean**	**Median**	**StdDev**	**StdErr**	**UCL 90%**	**LCL 90%**
Acer	54.774	56.977	15.445	2.774	59.337	50.211
Fraxinus	5.396	4.140	4.092	0.735	6.605	4.188
Malus	4.490	3.185	4.393	0.789	5.788	3.193
Gleditsia	4.304	2.986	4.179	0.751	5.538	3.069
Picea	4.162	3.822	3.286	0.590	5.132	3.191
Quercus	3.960	2.098	4.093	0.735	5.170	2.751
Tilia	3.551	2.064	3.651	0.656	4.630	2.473
Pyrus	2.245	1.745	2.711	0.487	3.046	1.444
Pinus	2.041	0.955	3.262	0.586	3.004	1.077
Ulmus	1.353	0.873	1.967	0.353	1.934	0.771
Prunus	1.342	0.867	1.417	0.255	1.760	0.923
Robinia	1.271	0.262	2.573	0.462	2.031	0.511
Platanus	0.101	0.000	0.300	0.054	0.189	0.012

Zone 5 (*n* = 60)	**Mean**	**Median**	**StdDev**	**StdErr**	**UCL 90%**	**LCL 90%**
Acer	55.880	55.869	12.163	7.214	67.747	44.013
Picea	5.706	4.305	5.188	0.737	6.918	4.495
Gleditsia	4.915	4.054	3.967	0.634	5.959	3.871
Malus	4.277	3.492	3.443	0.552	5.185	3.369
Fraxinus	3.693	3.391	2.657	0.477	4.477	2.909
Tilia	3.234	2.129	3.434	0.417	3.920	2.547
Quercus	2.895	2.256	2.498	0.374	3.510	2.281
Pyrus	2.423	1.853	2.475	0.313	2.937	1.908
Prunus	2.198	1.565	2.004	0.284	2.664	1.731
Pinus	1.713	0.967	2.243	0.221	2.077	1.349
Ulmus	0.904	0.604	0.889	0.117	1.096	0.712
Robinia	0.822	0.360	1.050	0.106	0.997	0.648
Platanus	0.654	0.378	0.868	0.084	0.792	0.515

Zone 6 (*n* = 28)	Mean	Medan	StdDev	StdErr	UCL 90%	LCL 90%
Acer	51.080	46.995	17.943	3.391	56.659	45.502
Gleditsia	6.164	5.523	4.089	0.773	7.436	4.893
Quercus	4.852	3.134	5.466	1.033	6.551	3.153
Tilia	4.472	2.640	4.527	0.856	5.879	3.065
Platanus	3.812	1.653	6.221	1.176	5.746	1.878
Fraxinus	3.713	2.119	3.138	0.593	4.689	2.738
Pyrus	3.302	2.022	4.391	0.830	4.667	1.936
Prunus	2.509	1.844	2.380	0.450	3.249	1.769
Malus	2.304	1.282	2.573	0.486	3.104	1.504
Picea	2.032	1.177	2.188	0.414	2.713	1.352
Ulmus	1.616	0.673	2.411	0.456	2.366	0.867
Pinus	1.351	0.738	1.556	0.294	1.835	0.867
Robinia	1.123	0.473	1.889	0.357	1.710	0.536

Zone 7 (*n* = 23)	Mean	Median	StdDev	StdErr	UCL 90%	LCL 90%
Acer	25.830	24.324	10.960	2.285	29.590	22.071
Quercus	13.142	12.868	9.275	1.934	16.323	9.961
Platanus	13.042	12.423	5.401	1.126	14.895	11.190
Pyrus	10.359	7.183	10.751	2.242	14.046	6.671
Tilia	4.559	3.426	3.693	0.770	5.826	3.293
Gleditsia	4.108	2.340	5.049	1.053	5.840	2.377
Prunus	4.048	3.829	1.989	0.415	4.730	3.366
Fraxinus	2.215	2.022	1.182	0.246	2.621	1.810
Pinus	1.694	0.588	1.862	0.388	2.332	1.055
Ulmus	1.501	0.898	2.052	0.428	2.205	0.797
Picea	1.389	0.310	1.747	0.364	1.988	0.790
Robinia	1.130	0.572	1.504	0.314	1.646	0.614
Malus	0.659	0.344	0.996	0.208	1.001	0.318

Species Composition

For each municipality from which data was obtained, trees were aggregated by species. The number of municipalities from which species data was obtained is less than the number of municipalities from which genus data was obtained primarily because some municipalities collect street tree data for genus (e.g. *Acer species*) but not for species (e.g. *Acer saccharum*). Trees categorized in the data as “unknown” were grouped as “Other.”

Similar to the methodology employed to generate statistics for street tree genera, the sum of all trees for each species was divided by the sum of all trees in each inventory to calculate a percentage for each species for each inventory accurate to three decimal points. These percentages were allocated to four zone classes (e.g. Zones 3 + 4, Zone 5, Zone 6, and Zone 7) based on the 1990 USDA Plant Hardiness Zones associated with their respective municipalities. Mean and median percentage, standard deviation, standard error, and upper and lower confidence levels (UCL and LCL) were calculated (α = .10) for all species in all zone classes.

Again, following the methodology employed for street tree genera, to determine the relative prevalence of street tree species statewide, the mean percentage of each species in each zone class was weighted by the relative percentage of summed street length expected to contain street trees for all

Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places within that zone class. Weighted mean percentages were ranked to determine relative prevalence statewide. Species whose weighted mean percentage was found to be at least 1.000% were judged to be prevalent. Together these species account for 72.255% of all trees for whom data was obtained. Table 3.4 shows statistics for the relative prevalence of street tree species statewide.

As with the genera statistics, percentages for some street tree species vary meaningfully between zone classes in Table 3.4. For example, *Acer saccharum* (Sugar Maple) is the most prevalent street tree species in Zones 3 + 4 and second most prevalent in Zone 5, but is much less prevalent in Zones 6 and 7. Similarly, *Malus species* (Crabapple Species) is more common in Zones 3 + 4 and Zone 5 and less common in Zones 6 and 7, while conversely *Pyrus calleryana* (Callery Pear) is more common in Zones 6 and 7 and less common in Zones 3 + 4 and Zone 5. This variation is illustrated in Figure 3.2.

Table 3.4 Relative prevalence of street tree species statewide (n = 132)

Species	**Zones 3 + 4 (Mean %, *n* = 28)**	**Zone 5 (Mean %, *n* = 57)**	**Zone 6 (Mean %, *n* = 29)**	**Zone 7 (Mean %, *n* = 18)**	**Weighted Mean %, All Zones**
Acer platanoides	15.524	21.248	28.359	14.729	20.653
Acer saccharum	20.612	20.190	5.626	2.665	9.892
Acer saccharinum	6.844	6.232	8.877	2.424	5.794
Platanus x acerifolia	0.057	0.485	3.283	13.551	5.722
Acer rubrum	6.243	5.288	5.498	4.859	5.294
Gleditsia triacanthos	4.222	4.853	6.205	4.875	5.210
Pyrus calleryana	2.281	2.440	3.184	8.534	4.718
Quercus palustris	0.661	0.760	2.397	5.265	2.773
Tilia cordata	2.295	2.277	3.238	2.646	2.694
Malus species	4.540	4.245	2.220	0.664	2.447
Fraxinus pennsylvanica	2.252	2.145	1.761	1.979	1.983
Quercus rubra	1.867	1.472	1.229	2.220	1.689
Picea abies	0.867	2.728	0.673	0.762	1.270
Pinus strobus	1.565	0.862	0.785	1.395	1.084
Robinia pseudoacacia	1.110	0.833	1.082	1.125	1.033

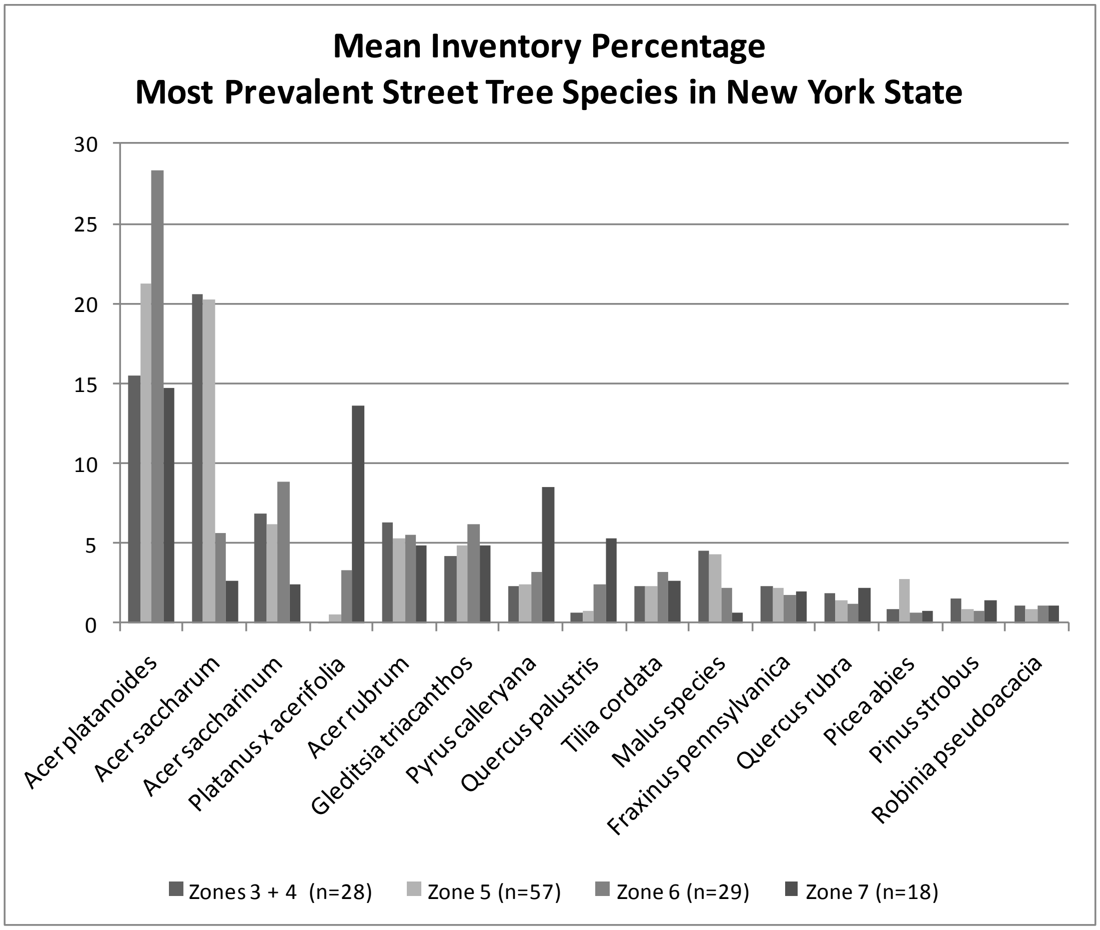


Figure 3.2 Mean inventory percentage for most prevalent street tree species in New York State by 1990 USDA Plant Hardiness Zone classes

Finally, summary statistics have been generated for prevalent street tree species in each zone class (i.e. Zones 3 + 4, Zone 5, Zone 6, and Zone 7). These statistics can be found in Table 3.5.

Table 3.5 Summary statistics for prevalent street tree species in New York State by 1990 USDA Plant Hardiness Zone classes

Zones 3 + 4 (*n* = 28)	**Mean**	**Median**	**StdDev**	**StdErr**	**UCL 90%**	**LCL 90%**
Acer saccharum	20.612	20.135	11.278	2.131	24.118	17.106
Acer platanoides	15.524	14.330	12.613	2.384	19.445	11.603
Acer saccharinum	6.844	3.708	10.151	1.918	10.000	3.688
Acer rubrum	6.243	5.727	3.648	0.689	7.377	5.109
Malus species	4.540	3.339	4.518	0.854	5.944	3.136
Gleditsia triacanthos	4.222	3.120	3.775	0.713	5.396	3.049
Tilia cordata	2.295	0.839	2.930	0.554	3.206	1.384
Pyrus calleryana	2.281	1.919	2.679	0.506	3.114	1.448
Fraxinus pennsylvanica	2.252	1.418	2.522	0.477	3.036	1.468
Quercus rubra	1.867	0.639	2.682	0.507	2.700	1.033
Pinus strobus	1.565	0.368	2.569	0.486	2.363	0.766
Robinia pseudoacacia	1.110	0.289	2.284	0.432	1.820	0.400
Picea abies	0.867	0.390	1.074	0.203	1.201	0.533
Quercus palustris	0.661	0.343	1.100	0.208	1.003	0.319
Platanus x acerifolia	0.057	0.000	0.178	0.034	0.113	0.002

Zone 5 (*n* = 57)	**Mean**	**Median**	**StdDev**	**StdErr**	**UCL 90%**	**LCL 90%**
Acer platanoides	21.248	20.234	10.270	1.360	23.485	19.010
Acer saccharum	20.190	17.702	14.253	1.888	23.296	17.085
Acer saccharinum	6.232	4.000	6.925	0.917	7.741	4.723
Acer rubrum	5.288	4.383	3.413	0.452	6.032	4.545
Gleditsia triacanthos	4.853	3.720	3.988	0.528	5.722	3.984
Malus species	4.245	3.415	3.508	0.465	5.010	3.481
Picea abies	2.728	2.000	2.625	0.348	3.300	2.156
Pyrus calleryana	2.440	1.910	2.506	0.332	2.986	1.894
Tilia cordata	2.277	1.189	2.743	0.363	2.875	1.680
Fraxinus pennsylvanica	2.145	1.439	2.457	0.325	2.680	1.609
Quercus rubra	1.472	1.095	1.333	0.177	1.762	1.181
Pinus strobus	0.862	0.219	1.641	0.217	1.219	0.504
Robinia pseudoacacia	0.833	0.355	1.070	0.142	1.066	0.600
Quercus palustris	0.760	0.261	1.403	0.186	1.066	0.455
Platanus x acerifolia	0.485	0.178	0.765	0.101	0.651	0.318

Zone 6 (*n* = 29)	Mean	Median	StdDev	StdErr	UCL 90%	LCL 90%
Acer platanoides	28.359	28.110	12.117	2.250	32.060	24.657
Acer saccharinum	8.877	4.252	11.001	2.043	12.238	5.517
Gleditsia triacanthos	6.205	5.686	3.931	0.730	7.405	5.004
Acer saccharum	5.626	3.518	5.877	1.091	7.421	3.831
Acer rubrum	5.498	3.963	5.953	1.105	7.316	3.680
Platanus x acerifolia	3.283	0.833	6.101	1.133	5.147	1.419
Tilia cordata	3.238	2.065	3.939	0.731	4.442	2.035
Pyrus calleryana	3.184	1.830	4.246	0.788	4.481	1.888
Quercus palustris	2.397	0.441	3.674	0.682	3.519	1.274
Malus species	2.220	1.235	2.496	0.463	2.982	1.458
Fraxinus pennsylvanica	1.761	0.833	2.190	0.407	2.430	1.092
Quercus rubra	1.229	0.714	1.269	0.236	1.616	0.841
Robinia pseudoacacia	1.082	0.417	1.835	0.341	1.643	0.522
Pinus strobus	0.785	0.093	1.315	0.244	1.187	0.383
Picea abies	0.673	0.311	1.218	0.226	1.045	0.301

Zone 7 (*n* = 18)	Mean	Median	StdDev	StdErr	UCL 90%	LCL 90%
Acer platanoides	14.729	12.493	9.141	2.155	18.274	11.185
Platanus x acerifolia	13.551	12.921	8.824	2.080	16.972	10.130
Pyrus calleryana	8.534	6.890	7.955	1.875	11.619	5.450
Quercus palustris	5.265	5.773	2.161	0.509	6.103	4.427
Gleditsia triacanthos	4.875	3.121	5.305	1.251	6.933	2.818
Acer rubrum	4.859	4.903	2.829	0.667	5.956	3.763
Acer saccharum	2.665	1.557	2.763	0.651	3.736	1.594
Tilia cordata	2.646	1.970	1.903	0.449	3.384	1.908
Acer saccharinum	2.424	2.380	1.506	0.355	3.008	1.840
Quercus rubra	2.220	1.961	1.204	0.284	2.687	1.753
Fraxinus pennsylvanica	1.979	1.859	1.197	0.282	2.444	1.515
Pinus strobus	1.395	0.307	1.728	0.407	2.066	0.725
Robinia pseudoacacia	1.125	0.724	1.261	0.297	1.614	0.636
Picea abies	0.762	0.104	1.080	0.255	1.181	0.343
Malus species	0.664	0.352	1.039	0.245	1.067	0.261

Relative Reliability of Genus and Species Composition

The reliability of summary statistics for genus and species composition, of rankings for genus and species prevalence, and of additional measures such as species and genus diversity depends to a great extent on the accuracy with which the genus and species of each inventoried street tree is identified. It is inevitable that mistakes will be found in any street tree inventory, whether data is collected by professionals or by volunteers. Regarding tree identification, it is more likely to find errors at the species level than at the genus level since, for example, it is typically easier to distinguish an oak (*Quercus*) from a maple (*Ace*r) than it is to distinguish Northern Red Oak (*Quercus rubra*) from Scarlet Oak (*Quercus coccinea*) or Black Oak (*Quercus velutina*).

In New York State, problems often arise in correctly identifying certain street tree species which can be difficult to distinguish such as Green Ash (*Fraxinus pennsylvanica*) and White Ash (*Fraxinus americana*). It is a concern that, if Green Ash trees are mistaken for White Ash trees, or vice-versa, individual inventory percentages of those species, where the sum of all trees for those species is divided by the sum of all trees in the inventory, may be incorrect which may in turn impact the relative percentages of those species statewide. Moreover, it is not uncommon to find in the data that some street trees are entered at the genus level (i.e. *Fraxinus* rather than *Fraxinus pennsylvanica*) while other trees are entered at the species level, or that a significant portion of a tree genus are entered simply as “species” (i.e. *Fraxinus species*). Such practices can introduce additional error into individual inventory percentages of tree species and impact the relative percentages of those species statewide. In some datasets, these practices have been found to be sufficiently pervasive that these datasets have been excluded from the analysis of statewide species composition less they bias statewide percentages for some tree species and have only been included in the analysis of statewide genus composition.

This is not to say that errors are not made at the genus level. For example, inventory data for one municipality in New York State indicated an unusually high percentage (18.48%) of Black Locust (*Robinia pseudoacacia*). Because Black Locust can be mistaken for Honeylocust (*Gleditsia triacanthos*) which is typically much more prevalent, most of the Black Locusts in the inventory were located in downtown sidewalk treelawns, and not a single Honeylocust was inventoried, a judgment was made that error had likely been made at the genus level and data for the municipality was excluded from this research. Nevertheless, an argument can reasonably be made that summary statistics for street tree genus composition are intrinsically more reliable than summary statistics for species composition and that this applies as well to genus and species prevalence and species and genus diversity. Accordingly, there would appear to be greater possibility of error in the relative statewide prevalence of a street tree species such as *Fraxinus pennsylvanica* than in the prevalence of a street tree species such as *Platanus x acerifolia* or *Pyrus calleryana*.

Species and Genus Diversity

As a general rule, no tree species should comprise more than 10% and no tree genera should comprise more than 20% of a municipality's street tree population (Santamour 1990). Bassuk et al (2009) have taken this rule further and proposed limiting any tree species to between 5% and 10% of a municipality's street tree population; Ball et al (2007) have recommended a 10% limit on genera based on full stocking; and Cummings et al (2004) suggest that diversity should be evaluated at taxonomic classification levels higher than genus such as family. Whatever the percentage or the level, the underlying principle is the same: diversity is a key component in the long term health of street tree populations. As was learned from the devastation wrought by Dutch elm disease to streets lined with American Elms, excessive planting of any tree species (i.e. low species diversity) renders a large proportion of a municipality's street tree population vulnerable to depredation from an insect or disease. Conversely, distributing plantings more equally among a range of tree species (i.e. high species diversity) reduces such vulnerability since, if any one species or genus becomes susceptible to an insect or disease, a majority of the municipality's street tree population will likely not be affected.

On a statewide basis, the percentage of *Acer* (44.135) exceeds the 20% rule for genera and the percentage of *Acer platanoides* (20.653) exceeds the 10% rule for species. Within the 1990 USDA Plant Hardiness Zone classes, the percentage of *Acer* exceeds the 20% rule for genera in all four zone classes (50.211, 55.880, 45.502, 22.071), the percentage of *Acer platanoides* exceeds the 10% rule for species in all four zone classes (15.524, 21.248, 28.359, 14.729) , the percentage of *Acer saccharum* exceeds the 10% rule for species in Zones 3 + 4 (20.612) and Zone 5 (20.190), and the percentage of *Platanus x acerifolia* (13.551) exceeds the 10% rule for species in Zone 7. Additional genera and species exceed the 20% and 10% rules within specific municipalities. For example, the percentages of *Tilia* (21.107) in Buffalo (Erie County, Zone 6) and *Pyrus* (36.375) in Garden City Park (Nassau County, Zone 7) exceed the 20% rule for genera, and the percentages of *Acer saccharinum* (49.448) in Cape Vincent (Jefferson County, Zones 3 + 4) and *Gleditsia triacanthos* (20.528) in Hilton (Monroe County, Zone 6) exceed the 10% rule for species.

Another measure of species diversity is Simpson's Diversity Index (SDI) which accounts for the number of species present in a population and the abundance of each species. Sun (1992) used the inverse of the SDI (i.e. 1/SDI) to study street tree populations in twenty-one cities and towns in the United States, United Kingdom, China, Greece, and Hong Kong. A larger inverse SDI value indicates greater species diversity and a smaller inverse

SDI value indicates less species diversity. Because the inverse SDI value represents the number of species if all species were evenly distributed in a population, an inverse SDI value of 10 approximates conformity with a 10% rule for species diversity and an inverse SDI value of 20 approximates conformity with a 5% rule for species diversity.

Inverse SDI values were calculated for the 132 municipalities from which street tree species data has been obtained. The mean inverse SDI and median inverse SDI were found to be 8.65 and 7.86 respectively. Only 36 of 131 municipalities (27.48%) were found to have an inverse SDI of at least 10.00. There was some variation in the inverse SDI values between municipalities by 1990 USDA Plant Hardiness Zone class: the mean inverse SDI value for Zone 7 (11.79) was significantly higher than the mean inverse SDI values for Zones 3 + 4 (8.08), Zone 5 (8.16), and Zone 6 (8.20). Finally, inverse SDI values for all municipalities were found to be weakly correlated with municipal population size (.12) and population density (.11).

The Shannon-Weiner Diversity Index is sometimes preferred to the SDI because the SDI weights the most abundant species more heavily than the less abundant species; on the other hand, SDI values are less sensitive to variation in sample size (Barbour et al 1987). McPherson and Rowntree (1989) used the Shannon-Weiner Diversity Index to measure street tree species diversity for twenty-two municipalities in the United States including two in New York State, the City of Syracuse and the Village of Great Neck Estates. Shannon-Weiner values ranged from 2.1 to 3.9 and the mean for all municipalities was 2.7. McPherson and Rowntree found that species diversity was greatest in municipalities with milder climates and attributed the higher values in these cities more to the larger number of species than to the evenness of species distribution.

Shannon-Weiner values were calculated for the 132 municipalities from which street tree species data has been obtained. Mean and median values were found to be 2.66 and 2.67 respectively with a range from 1.73 to 3.92. Similar to results for inverse SDI values, there was some variation in Shannon-Weiner values between municipalities by 1990 USDA Plant Hardiness Zone class: the mean Shannon-Weiner value for Zone 7 (2.95) was significantly higher than the mean Shannon-Weiner values for Zones 3 + 4 (2.55), Zone 5 (2.64), and Zone 6 (2.60). Consistent with the findings made by McPherson and Rowntree, higher Shannon-Weiner values were correlated more with a larger number of species (0.62) than with the evenness of species distribution (0.23). Finally, and again similar to results for inverse SDI values, Shannon-Weiner values for all municipalities were found to be weakly correlated with municipal population size (.14) and population density (.13).

Thus, results for inverse SDI and Shannon-Weiner values coupled with summary statistics for genus and species composition reveal insufficient species and genus diversity in New York State street trees. Consistent with the findings made by McPherson and Rowntree, species diversity increased with milder temperatures and higher species diversity should be attributed more to a larger number of species than to the evenness of species distribution. Although species diversity was found to be appreciably greater in Zone 7 than in Zones 3 + 4, 5, and 6, even for Zone 7 where Acer (22.071) exceeds the 20% rule for genera and *Acer platanoides* (14.729) and *Platanus x acerifolia* (13.551) exceed the 10% rule for species, diversity should be increased to reduce street tree population vulnerability to depredation from an insect or disease. Of particular worry in this respect is the Asian Longhorned Beetle (ALB), an invasive pest which has been found in New York City, on Long Island, and elsewhere in the United States and Canada. Because *Acer* is among the tree genera attacked and killed by the ALB, and *Acer* species have been excessively planted as street trees in New York State, a large proportion of the New York State street tree population is vulnerable to the ALB. Therefore, new street tree plantings statewide should de-emphasize trees in the *Acer* genus.

Relative Age Distribution

Another component in the long term health of street tree populations is the relative age distribution of street trees. There needs to be a sufficient number of younger, smaller trees to account for the loss of trees over time in order to maintain a sustainable street tree population. Because of mortality among both newly planted trees failing to achieve maturity and older trees reaching the end of their life cycle, the number of younger trees should exceed the number of older trees, creating a j-shaped profile in the relative age distribution. Figure 3.3 contains two graphs depicting contrasting age distribution profiles in street tree populations with tree diameter measured at breast height (DBH). The j-shaped profile on the left depicts a sustainable street tree population with sufficient younger, smaller trees to account for the loss of trees over time. The inverted v-shaped profile on the right depicts a street tree population not sustainable over time because it contains insufficient younger trees and a disproportionate share of older trees.

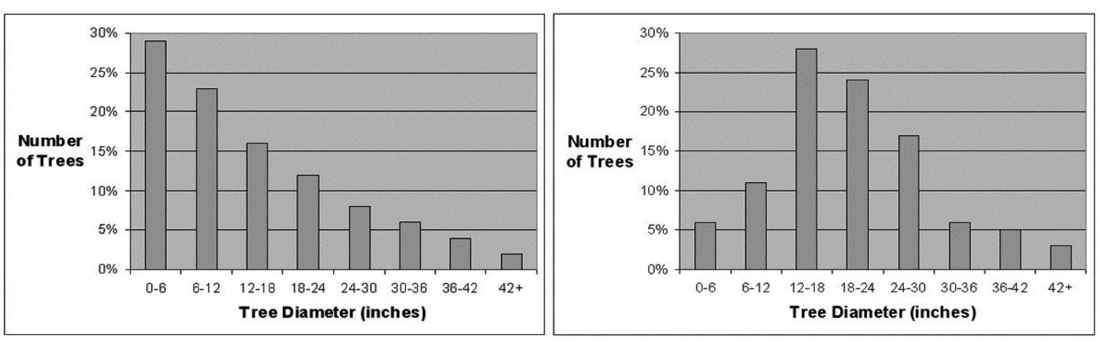


Figure 3.3 Street tree population relative age distribution profiles

In the sustainable j-shaped relative age distribution profile, approximately 30% of a street tree population is contained within the 0 to 6 inch DBH class. Another profile of DBH distribution has been postulated by Richards (1983) such that a sustainable distribution of street trees would find 40% of trees with a DBH less than 8 inches, 30% of trees with a DBH 8 to 16 inches, 20% of trees with a DBH 16 to 24 inches, and 10% of trees with a DBH greater than 24 inches. While Richards's profile accounts for approximately 12.5% more trees within a DBH 0 to 24 inch class than does the sustainable j-shaped relative age distribution profile and also accounts for slightly more trees within the 0 to 6 inch DBH class than does sustainable j-shaped relative age distribution profile, the sustainable j-shaped relative age distribution profile and DBH classes in 6 inch intervals are much more widely used in urban forestry. Therefore, DBH classes in 6 inch intervals, including the 0 to 6 inch DBH class and the 30% benchmark for that class, will be used in the subsequent analysis of the relative age distribution of street trees in New York State.

For each municipality from which data was obtained, trees were aggregated into the following eight DBH classes: 0 to 5.9 inches, 6 to 11.9 inches, 12 to 17.9 inches, 18 to 23.9 inches, 24 to 29.9 inches, 30 to 35.9 inches, 36 to 41.9 inches, and 42 inches and greater. The number of municipalities for which DBH data was aggregated is less than the number of municipalities from which genus data was obtained because DBH data was not collected for some municipalities or DBH data was collected in classes other than those specified above. For each municipality, aggregated DBH data was converted to a percentage of all trees in the inventory for each DBH class. Percentages were allocated to the 1990 USDA Plant Hardiness Zone class associated with the municipality. Means for each zone class were calculated and weighted in a manner similar to genus and species composition (i.e. by the relative percentage of summed street length expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places within that zone class – see Table 3.1).   Figure 3.4 depicts a statewide distribution of New York State street trees by DBH class. Its profile corresponds more closely to the street tree population age profile in Figure 3.3 judged to be not sustainable because it contains insufficient younger trees and a disproportionate share of older trees. It indicates that increased numbers of street trees need to be planted statewide to maintain street tree populations at current levels.

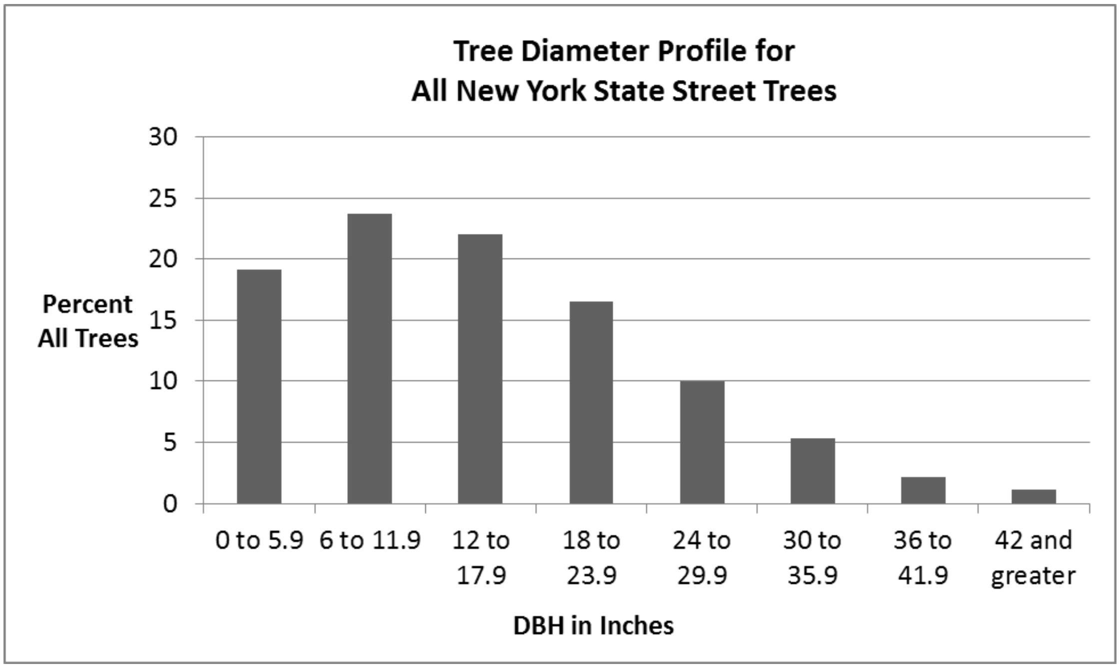


Figure 3.4 Tree diameter (DBH) profile for all New York State street trees

Data for the 0 to 5.9 inch DBH class was selected for the most prevalent street tree species identified in Table 3.4. Although some trees contained in this class may be "volunteers," especially in more rural and/or less densely populated places, this DBH class represents street trees most recently planted and indicates trends in the population. Table 3.6 compares the relative abundance of the most prevalent street tree species for all DBH classes to the relative abundance of the most prevalent street tree species for only the 0 to 5.9 inch DBH class.

Table 3.6 Relative abundance for most prevalent street tree species

	All Trees, Weighted Mean %, All Zones	Trees DBH 0” to 5.9”, Weighted Mean %, All Zones	% Change
Acer platanoides	20.653	12.924	–37.42%
Acer saccharum	9.892	4.158	–57.97%
Acer saccharinum	5.794	1.315	–77.30%
Platanus x acerifolia	5.722	1.085	–81.04%
Acer rubrum	5.294	6.313	+19.24%
Gleditsia triacanthos	5.210	4.810	–7.68%
Pyrus calleryana	4.718	8.787	+86.24%
Quercus palustris	2.773	1.186	–57.25%
Tilia cordata	2.694	3.065	+13.78%
Malus species	2.447	5.697	+132.80%
Fraxinus pennsylvanica	1.983	1.829	–7.77%
Quercus rubra	1.689	1.873	+10.88%
Picea abies	1.270	0.770	–39.37%
Pinus strobus	1.084	1.345	+24.06%
Robinia pseudoacacia	1.033	0.473	–54.20%

Table 3.6 results suggest that tree species such as *Platanus x acerifolia* (London Plane), *Acer saccharinum* (Silver Maple), and *Acer saccharum* (Sugar Maple) are being planted less frequently and their percentage of the statewide street tree population is likely to decline while tree species such as *Malus species* (Crabapple), *Pyrus calleryana* (Callery Pear), and *Quercus rubra* (Northern Red Oak) are being planted more frequently and their percentage of the statewide street tree population is likely to increase. This trend reflects to some extent wise horticultural practice since *Acer saccharinum* is a large, rapidly growing tree species susceptible to branch failure whose use as a street tree has been discouraged (Gilman & Watson 1993). However, it is also suggests that more small and medium sized street trees (i.e. mature height less than 60 feet) are being planted relative to large sized street trees (i.e. mature height greater than 60 feet).

Table 3.7 allocates the results from Table 3.6 into two tree size classes, small and medium sized trees and large sized trees, based on estimates for mature growing heights derived from i-Tree's tree species database for the Northeast Climate Zone (USDA Forest Service 2008a). It reaffirms the trend suggested by Table 3.6 that small and medium sized trees have been increasingly planted in New York State relative to large sized trees for the most prevalent street tree species. A similar trend was identified by McPherson and Rowntree (1989) for twenty-two municipalities in the United States, and by Bernhardt and Swiecki (1993) and Thompson (2006) statewide in California.

Table 3.7 Percentage change for most prevalent street tree species, small and medium sized trees and large sized trees

Small and Medium Sized Trees	
Acer rubrum	
Pyrus calleryana	
Tilia cordata	
Malus species	
Mean Percentage Change	+57.47%
Large Sized Trees	
Acer platanoides	
Acer saccharum	
Acer saccharinum	
Gleditsia triacanthos	
Platanus x acerifolia	
Quercus palustris	
Fraxinus pennsylvanica	
Quercus rubra	
Picea abies	
Pinus strobus	
Robinia pseudoacacia	
Mean Percentage Change	–44.37%

Attempting to explain this trend, both Bernhardt and Swiecki and Thompson found that street tree species selection was driven primarily by two criteria: planting site space limitations and reduction in tree maintenance costs (the assumption being made that small and medium sized street trees are less costly to maintain than large sized street trees). These criteria may be operational in New York State as well. In addition, however, electric utility companies in New York State such as National Grid have promoted planting small sized street trees (i.e. mature height less than 30 feet) and not medium and large sized street trees under electric utility wires (National Grid 2011).

To further explore these trends, 103 inventories for which tree species and DBH data was available were analyzed. The mean percentage of small sized tree species and medium and large sized tree species was calculated for all trees and for trees with a DBH ≤ 6 inches. Results are shown in Figure 3.5.

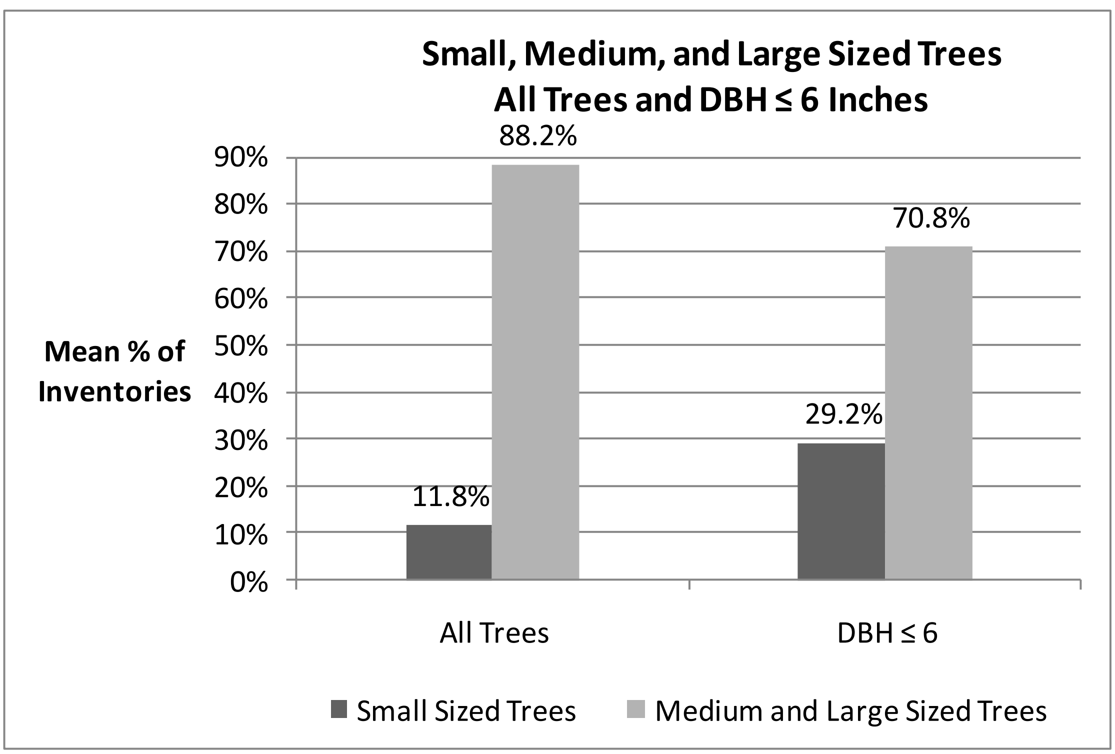


Figure 3.5 Mean percentage of inventory data (n = 103) for small, medium, and large sized street trees comparing all trees to trees with a DBH ≤ 6 inches

In addition, 31 inventories for which tree species, DBH, and utility wire data was available was analyzed such that the mean percentage of trees for small sized tree species and medium and large sized tree species was calculated for all trees and for trees with a DBH ≤ 6 inches. Results are shown in Figure 3.6.

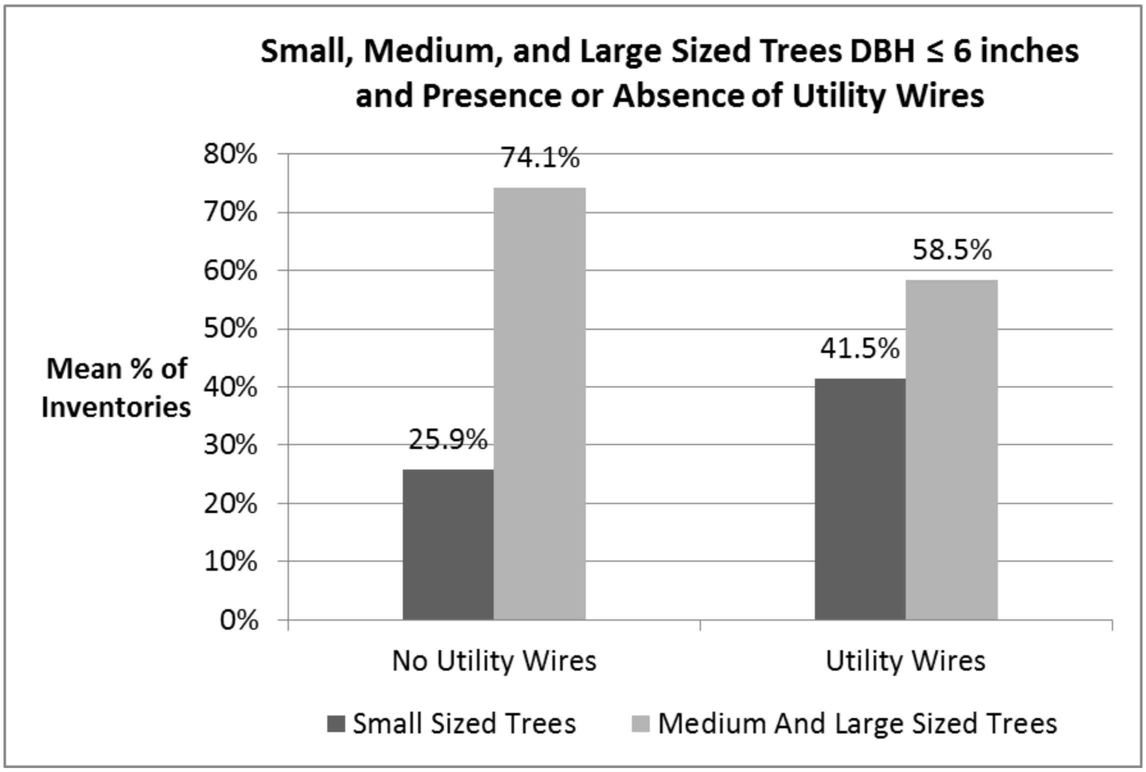


Figure 3.6 Mean percentage of inventory data (n = 31) for small, medium, and large sized street trees with the presence or absence of single or triple phase utility wires

Results shown in Figures 3.5 and 3.6 suggest that, similar to the trend identified for the most prevalent statewide street tree species (Table 3.7) and findings made by McPherson and Rowntree (1989), Bernhardt and Swiecki

(1993), and Thompson (2006), there is a trend towards increased plantings of smaller sized street tree species relative to plantings of larger sized street tree species. In addition, while some of this increase may be attributed to planting smaller sized street tree species below utility wires in order to avoid conflicts with them, the presence or absence of overhead utility wires does not fully explain this increase. In other words, smaller sized street tree species are being planted increasingly whether electric utility wires are overhead or not.

Planting site space limitations have also been named by Bernhardt and Swiecki (1993) and Thompson (2006) as a factor contributing to increased plantings of small and medium sized street trees relative to large sized street trees. Accordingly, for 30 inventories in which tree species, DBH, and location site type data were available, a count was made for the most prevalent street tree species specified in Table 3.6 for each of four location site types: front yard or lawn, treelawn (strip between sidewalk and street curb), sidewalk pit, and other (median, unmanaged areas, etc.), for all trees contained in the 30 inventories (n = 54449) and all trees contained in the 30 inventories with a DBH < 6 inches (n = 9303). The percentage of street tree species per location site type was calculated for all street trees contained in the 30 inventories and all street trees contained in the 30 inventories with DBH < 6 inches. Table 3.8 and Table 3.9 contain results of this analysis. Table 3.8 shows the distribution by location site type for each street tree species. Table 3.9 shows the distribution by street tree species for each location site type.

Table 3.8 Distribution by location site type for each street tree species

All Trees	% Front Yard	% Treelawn	% Sidewalk Pit	% Other
Acer platanoides	37.73%	58.47%	1.27%	2.53%
Acer saccharum	53.66%	41.89%	1.59%	2.86%
Acer saccharinum	42.58%	53.65%	0.80%	2.98%
Acer rubrum	50.73%	44.32%	0.89%	4.06%
Gleditsia triacanthos	35.38%	48.19%	12.25%	4.18%
Platanus x acerifolia	74.67%	24.21%	0.92%	0.20%
Pyrus calleryana	31.68%	48.96%	16.00%	3.36%
Tilia cordata	25.52%	63.02%	10.61%	0.85%
Malus species	24.47%	64.26%	4.15%	7.13%
Quercus palustris	47.60%	42.21%	6.86%	3.33%
Fraxinus pennsylvanica	38.63%	52.46%	3.35%	5.56%
Quercus rubra	66.70%	29.69%	1.13%	2.47%
Picea abies	86.21%	4.91%	0.00%	8.89%
Pinus strobus	89.76%	2.44%	0.16%	7.64%
Robinia pseudoacacia	75.09%	13.23%	0.00%	11.68%

Trees DBH < 6 inches	% Front Yard	% Treelawn	% Sidewalk Pit	% Other
Acer platanoides	31.44%	64.35%	1.64%	2.57%
Acer saccharum	42.10%	53.34%	3.50%	1.06%
Acer saccharinum	46.67%	50.00%	3.33%	0.00%
Acer rubrum	37.97%	53.22%	3.73%	5.08%
Gleditsia triacanthos	25.06%	53.76%	15.49%	5.69%
Platanus x acerifolia	55.88%	33.82%	7.35%	2.94%
Pyrus calleryana	41.34%	46.81%	10.33%	1.52%
Tilia cordata	26.56%	51.88%	21.25%	0.31%
Malus species	30.82%	56.62%	3.35%	9.21%
Quercus palustris	30.91%	61.82%	7.27%	0.00%
Fraxinus pennsylvanica	31.49%	62.98%	3.83%	1.70%
Quercus rubra	48.62%	44.04%	2.75%	4.59%
Picea abies	84.11%	10.28%	0.00%	5.61%
Pinus strobus	95.20%	4.80%	0.00%	0.00%
Robinia pseudoacacia	74.19%	12.90%	0.00%	12.90%

Percent Change	% Front Yard	% Treelawn	% Sidewalk Pit	% Other
Acer platanoides	-20.02%	10.06%	29.08%	1.73%
Acer saccharum	-27.46%	27.33%	119.93%	-168.91%
Acer saccharinum	9.61%	-7.30%	317.42%	NA
Acer rubrum	-33.62%	20.07%	318.77%	25.35%
Gleditsia triacanthos	-41.18%	11.56%	26.42%	36.14%
Platanus x acerifolia	-33.62%	39.70%	698.80%	1406.30%
Pyrus calleryana	30.48%	-4.60%	-54.82%	-121.09%
Tilia cordata	4.07%	-21.48%	100.34%	-172.26%
Malus species	25.96%	-13.50%	-23.75%	29.24%
Quercus palustris	-54.00%	46.44%	6.08%	NA
Fraxinus pennsylvanica	-22.68%	20.05%	14.32%	-226.62%
Quercus rubra	-37.18%	48.32%	142.70%	85.40%
Picea abies	-2.49%	109.50%	NA	-58.47%
Pinus strobus	6.07%	96.80%	NA	NA
Robinia pseudoacacia	-1.20%	-2.53%	NA	10.44%

Table 3.9 Distribution by street tree species for each location site type

All Trees	% Front Yard	% Treelawn	% Sidewalk Pit	% Other
Acer platanoides	17.454%	32.733%	9.656%	15.823%
Acer saccharum	6.080%	5.745%	2.962%	4.382%
Acer saccharinum	4.225%	6.442%	1.303%	3.992%
Acer rubrum	7.387%	7.811%	2.133%	7.984%
Gleditsia triacanthos	3.868%	6.377%	22.038%	6.183%
Platanus x acerifolia	9.642%	3.783%	1.955%	0.341%
Pyrus calleryana	1.426%	2.667%	11.848%	2.045%
Tilia cordata	1.621%	4.842%	11.078%	0.730%
Malus species	1.743%	5.540%	4.858%	6.865%
Quercus palustris	1.750%	1.879%	4.147%	1.655%
Fraxinus pennsylvanica	1.952%	3.208%	2.784%	3.797%
Quercus rubra	2.330%	1.255%	0.652%	1.168%
Picea abies	2.341%	0.161%	0.000%	3.262%
Pinus strobus	1.988%	0.065%	0.059%	2.288%
Robinia pseudoacacia	1.574%	0.336%	0.000%	3.311%

Trees DBH < 6 inches	% Front Yard	% Treelawn	% Sidewalk Pit	% Other
Acer platanoides	9.861%	18.733%	4.015%	11.419%
Acer saccharum	6.778%	7.970%	4.398%	2.422%
Acer saccharinum	1.028%	1.022%	0.574%	0.000%
Acer rubrum	2.740%	3.565%	2.103%	5.190%
Gleditsia triacanthos	2.691%	5.359%	13.002%	8.651%
Platanus x acerifolia	0.930%	0.522%	0.956%	0.692%
Pyrus calleryana	6.655%	6.994%	13.002%	3.460%
Tilia cordata	2.080%	3.769%	13.002%	0.346%
Malus species	4.502%	7.675%	3.824%	19.031%
Quercus palustris	0.832%	1.544%	1.530%	0.000%
Fraxinus pennsylvanica	1.811%	3.361%	1.721%	1.384%
Quercus rubra	1.297%	1.090%	0.574%	1.730%
Picea abies	2.202%	0.250%	0.000%	2.076%
Pinus strobus	2.912%	0.136%	0.000%	0.000%
Robinia pseudoacacia	0.563%	0.091%	0.000%	1.384%

Percent Change	% Front Yard	% Treelawn	% Sidewalk Pit	% Other
Acer platanoides	-77.01%	-74.74%	-140.49%	-38.57%
Acer saccharum	11.48%	38.74%	48.47%	-80.90%
Acer saccharinum	-311.12%	-530.46%	-127.21%	NA
Acer rubrum	-169.57%	-119.10%	-1.40%	-53.83%
Gleditsia triacanthos	-43.73%	-19.00%	-69.50%	39.91%
Platanus x acerifolia	-937.02%	-624.42%	-104.49%	103.06%
Pyrus calleryana	366.61%	162.18%	9.74%	69.22%
Tilia cordata	28.32%	-28.47%	17.36%	-111.05%
Malus species	158.26%	38.54%	-27.03%	177.23%
Quercus palustris	-110.42%	-21.66%	-171.10%	NA
Fraxinus pennsylvanica	-7.82%	4.76%	-61.80%	-174.37%
Quercus rubra	-79.70%	-15.17%	-13.61%	48.07%
Picea abies	-6.31%	54.88%	NA	-57.12%
Pinus strobus	46.45%	108.38%	NA	NA
Robinia pseudoacacia	-179.69%	-269.51%	NA	-139.19%

Planting site space limitations are usually most restrictive for sidewalk pits and least restrictive for front yards and lawns. Treelawn restrictiveness varies greatly depending on the width and length of the area between sidewalk and curb, but can be assumed to fall somewhere between sidewalk pits and front yards. Additionally, soil compaction, an important factor in street tree species selection and tree growth and survivability, can be assumed to be greater for sidewalk pits and treelawns than for front yards and lawns.

Results contained in Table 3.8 and Table 3.9 suggest that smaller sized street tree species such as *Malus species* and *Pyrus calleryana* are being planted increasingly in front yards and lawns, both as a percentage of each species and as a percentage of location site type, thereby occupying planting sites where space limitations are typically least restrictive. Conversely, larger sized street tree species, such as *Acer platanoides*, *Platanus x acerifolia*, *Quercus palustris*, and *Quercus rubra* are being planted less frequently in front yards and lawns, both as a percentage of each species and as a percentage of location site type. Results are similar for treelawns: *Malus species* and *Pyrus calleryana* are being planted increasingly in treelawns as a percentage of location site type, but less frequently as a percentage of each species, perhaps reflecting the increase in front yard plantings; *Acer platanoides*, *Platanus x acerifolia*, *Quercus palustris*, and *Quercus rubra* are being planted less frequently in treelawns as a percentage of location site type, but more frequently as a percentage of each species. Finally, results for sidewalk pits are mixed: *Acer saccharum*, *Pyrus calleryana*, and *Tilia cordata* are being planted increasingly in sidewalk pits as a percentage of location site type while *Acer platanoides, Platanus x acerifolia*, and *Malus species* are being planted less frequently.

These results generally confirm the findings made by McPherson and Rowntree (1989), Bernhardt and Swiecki (1993), and Thompson (2006) of a trend towards increased plantings of smaller sized street tree species relative to plantings of larger sized street tree species. Causal factors for this trend are not entirely clear. Planting smaller sized street tree species below overhead utility wires in order to minimize conflicts between trees and wires appears to be part of the explanation. However, less convincing as a causal factor is planting site space limitations given findings of increased plantings of smaller sized street tree species and fewer plantings of larger sized street tree species in front yards and lawns where planting site space limitations are least restrictive and, to a lesser extent, in treelawns where planting site space limitations are more restrictive than front yards and lawns, but less restrictive than sidewalk pits. It is possible that pursuit of reductions in street tree maintenance costs may be a causal factor although it is not possible to ascertain this from the current data. It is also possible that aesthetic preference could be part of the explanation and that more smaller sized street tree species are being planted relative to larger sized street tree species because smaller, flowering tree species are preferred to larger growing shade tree species.

Whatever the reasons underlying a trend towards increased plantings of smaller sized street tree species relative to plantings of larger sized street tree species, the implications are not merely aesthetic. As Bernhardt and Swiecki (1993) and Thompson (2006) have pointed out, the trend towards planting small and medium sized street trees rather than large sized street trees reduces environmental and social benefits provided by street trees. Since most benefits provided by trees are a function of leaf surface area and large sized trees have more leaf surface area than small and medium sized trees, larger sized trees are able to absorb and sequester more carbon than smaller trees and remove larger quantities of pollutants (Nowak et al 2002). Therefore, the trend towards increased plantings of smaller sized street tree species relative to plantings of larger sized street tree species comes at the expense of energy conservation, air quality improvement, and stormwater reduction and lowers the structural ceiling of benefits potentially provided by street trees. If the environmental and social benefits provided by street trees are to be prioritized, more large sized street tree species need to be planted relative to small and medium sized street tree species than is happening currently.

Street Tree Benefits

Research has shown that urban and community trees provide ecological and social benefits including energy conservation (McPherson & Rowntree 1993), stormwater reduction (Xiao et al 1998), air and water pollution abatement (Brack 2002), carbon storage and sequestration (Nowak & Crane 2002), and increased real estate values (Anderson & Cordell 1988). To encourage public awareness of these benefits and to support urban and community tree management, the USDA Forest Service developed the i-Tree suite of computer software programs, including UFORE (Urban Forest Effects Model) and STRATUM (Street Tree Resource Analysis Tool for Urban Forest Managers), to facilitate the collection of urban and community tree data and quantify the benefits provided by trees derived from this data. STRATUM, created specifically for street trees and since renamed Streets, quantifies in dollar values the annual ecological and social benefits provided by street trees in five categories: energy conservation, air quality improvement, CO_2 reduction, stormwater control, and property value increase (USDA Forest Service 2011). It requires collection at a minimum of species and DBH data for each tree surveyed. Benefits can be calculated from a complete street tree inventory where all street trees in a municipality have been surveyed or from a sample street tree inventory where data has been collected consistent with a sampling methodology (i.e. stratified by land use, 2000 to 2200 tree minimum) devised by Jaensen et al (1992).

Benefits calculated by i-Tree STRATUM and Streets are estimates. Most of these estimates are predicated on and are proportional to the amount of tree leaf surface area (LSA), the sum of all tree leaf surfaces. Leaf surface area must be differentiated from leaf area index (LAI), or the total one-sided area of leaf tissue per unit ground surface area (Breda 2003). Leaf surface area varies by tree type (deciduous, evergreen) and species, and leaf surface area by species is estimated from computer processing of tree-crown imagery, a technique whose accuracy has been found to be ± 20% of actual leaf surface area (Peper & McPherson 2003). Leaf surface area by species as predicted by DBH is based on best fit statistical modeling (Peper et al 2001). Tree growth rates are estimated from street trees stratified by size (small, medium, large) and type randomly sampled in a reference city within an i-Tree climate zone. According to McPherson (2010), i-Tree climate zones are derived from climate zones delineated by the Sunset Publishing Corporation (Brenzel 1997) and ecoregions delineated by Bailey (2002) and Breckle (1999). Each i-Tree climate zone contains one reference city. Modeling results from the reference city are extrapolated to other municipalities within the same climate zone and should be limited to municipalities within that climate zone (Peper et al 2001). It is important to note that i-Tree climate zone boundaries do not conform to 1990 USDA Plant Hardiness Zones. Municipalities located within different 1990 USDA Plant Hardiness Zones may be associated with the same i-Tree climate zone. Figure 3.7 illustrates the i-Tree climate zones for the United States (USDA Forest Service (2010d).

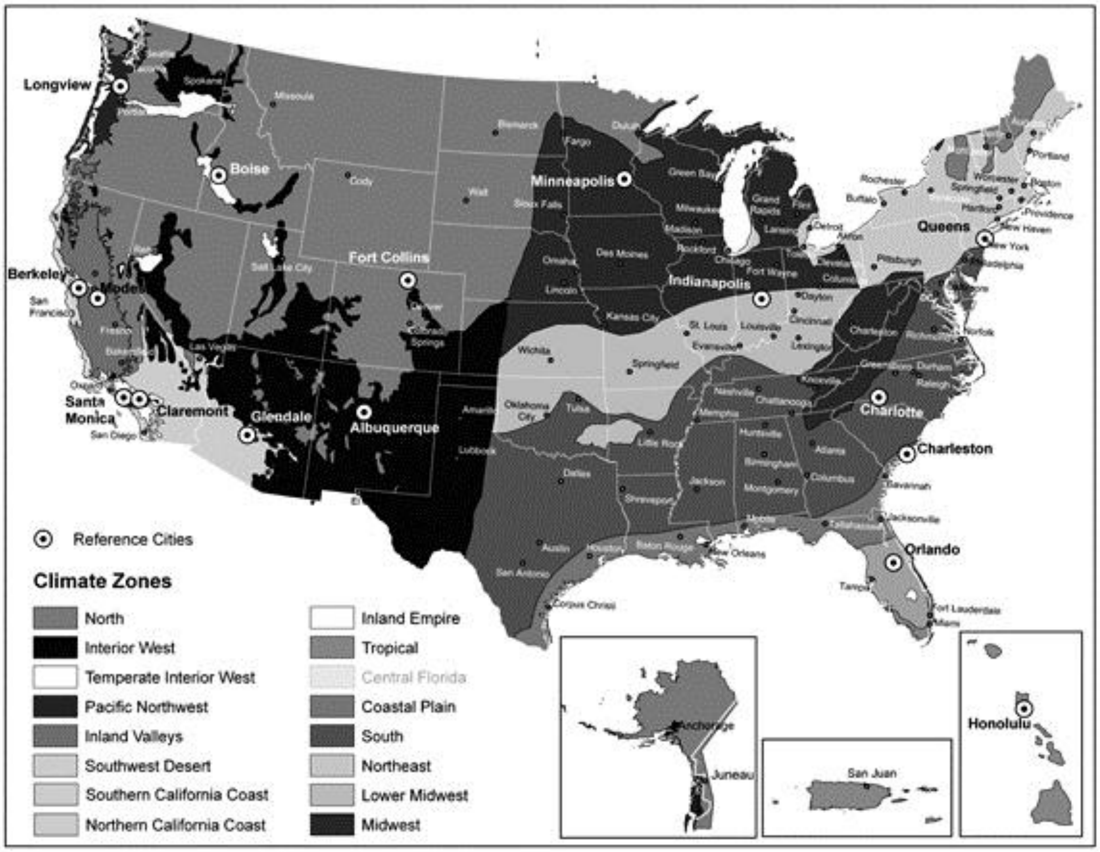


Figure 3.7 i-Tree climate zones for the United States

Most of New York State and nearly all its populated communities are located within i-Tree's Northeast climate zone. The reference city for the Northeast climate zone is the Borough of Queens in New York City. On average, data for twenty-two tree species are collected in a reference city; in Queens, NY, data for twenty-one tree species were collected (McPherson et al 2007). A part of northern St. Lawrence County is associated with the Midwest climate zone for which the reference city is Minneapolis, MN, and contains the city of Ogdensburg, the villages of Heuvelton, Massena, Norwood, Rensselaer Falls, and Waddington, and the CDP of Norfolk. The Adirondack region is located in the North climate zone for which the reference city is Fort Collins, CO, and contains the villages of Burke, Chateaugay, Dannemora, Lake Placid, Northville, Saranac Lake, Speculator, and Tupper Lake, and the CDPs of Altona, Au Sable Forks, Lyon Mountain, and Redford. Figure 3.8 illustrates the i-Tree climate zones for New York State (USDA Forest Service (2010d).

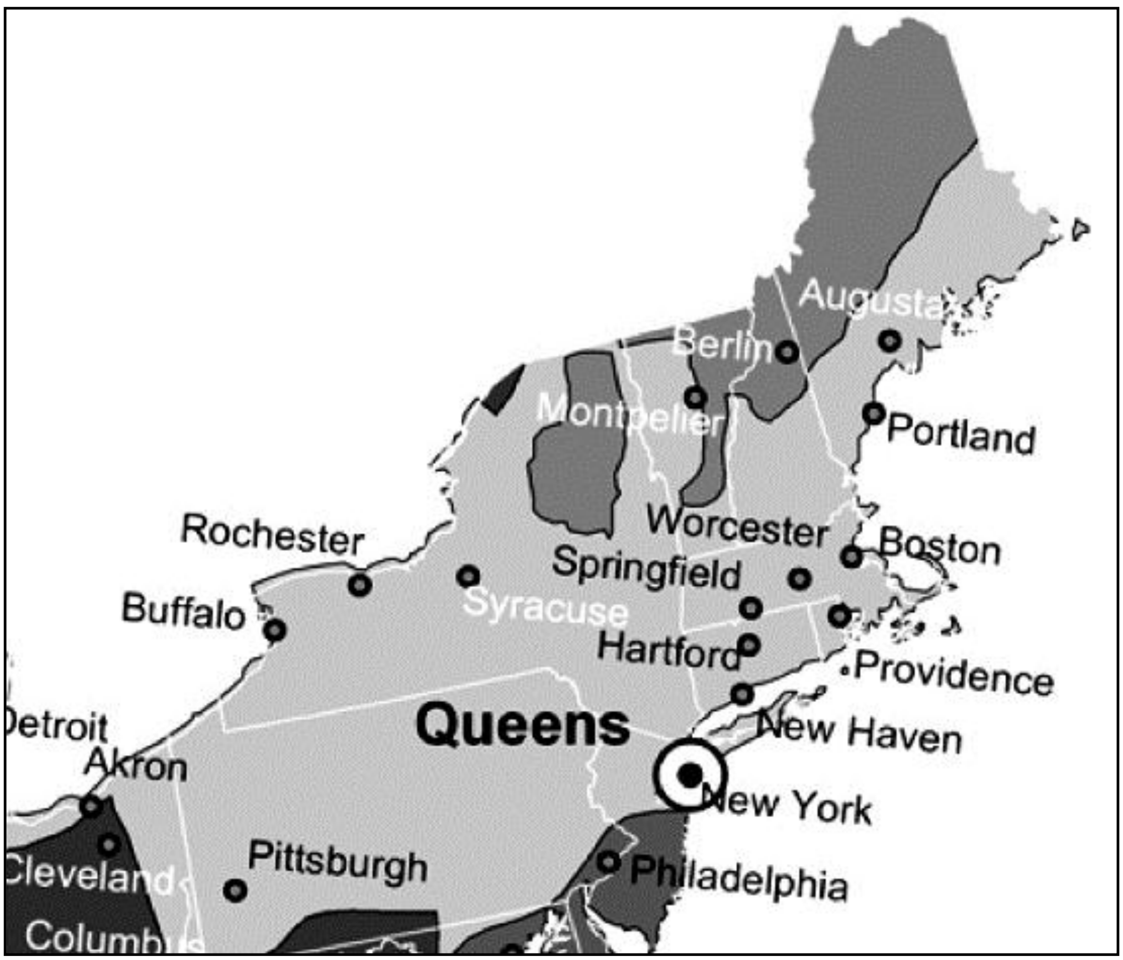


Figure 3.8 i-Tree climate zones for New York State

As McPherson (2010) admits, although inputs affecting benefit calculations such as the cost of generating electricity or of treating stormwater runoff can be customized in i-Tree STRATUM and Streets for each municipality, benefit calculations are simulations that approximate reality. The reliance on a reference city is a particular concern:

> It is recognized that relying on reference city data is a poor substitute for applying local data. Results are, at best, first-order approximations due to extrapolation of data from reference city to subject city.

In other words, extrapolating modeling results from Queens to Binghamton, Minneapolis to Ogdensburg, or Fort Collins to Lake Placid is not fundamentally desirable. Nevertheless, despite limitations and caveats, benefits calculated by i-Tree STRATUM and Streets provide a useful metric for evaluating street trees within and between municipalities. Metrics for evaluating street trees have most often consisted of a count of street trees per unit measure such as street length. For example, in considering street trees as a pedestrian amenity affecting pedestrian mobility, safety, and comfort, the GIS protocols of the Twin Cities Walking Study (2007) calculated a density measure based on the number of street trees per length of road within an area. Similarly, to explore possible relationships between street trees and childhood asthma in New York City, Lovasi et al (2008) correlated the total number of trees on street segments both contained within and divided by hospital catchment areas with prevalence of childhood asthma and hospitalizations for the same. Related metrics are street trees per capita, or the number of street trees in an area divided by the area's population (McPherson & Rowntree 1989), and stocking level, or the number of street trees planted as a percentage of all available planting sites, whether those sites contain trees or not.

Metrics evaluating street trees based on a street tree count contain a fundamental flaw, namely that they give all trees equal weight regardless of species type and size, thereby failing to account for significant differences in ecosystem benefits provided primarily by the greater amount of leaf surface area associated with a large statured tree compared to the reduced amount of leaf surface area associated with a smaller statured tree (Nowak et al 2002). To paraphrase Gertrude Stein, a tree is not a tree is not a tree. Tree species and tree size need to be accounted for, especially if ecosystem and social benefits are to be included in street tree evaluation metrics. In other words, evaluating street trees more comprehensively requires moving beyond metrics based on street tree counts to metrics that account for ecosystem and social benefits. i-Tree STRATUM and Streets provide an opportunity to create these latter, more comprehensive type of metrics although the limitations inherent in the methods and models on which they are based must be recognized.

For 123 municipalities where tree species and DBH data was available, including sample and partial street tree inventories, i-Tree Streets was used to calculate total annual benefits (energy conservation, air quality improvement,

CO_2 reduction, stormwater control, and property value increase) provided by inventoried street trees in that municipality. Total annual benefits (in dollars) per community were divided by the number of street trees surveyed in that community to calculate benefits per street tree per community (in dollars). Mean benefits per street tree were found to be 133.75 with a median of 135.57, a standard deviation of 24.05, a standard error of 2.17, and upper and lower confidence levels (α = .10) of 137.32 and 130.18. Benefits per street tree per community were allocated to four zone classes (e.g. Zones 3 + 4, Zone 5, Zone 6, and Zone 7) based on the 1990 USDA Plant Hardiness Zones associated with their respective municipalities. Mean and median figures, standard deviation, standard error, and upper and lower confidence levels (α = .10) were calculated for all zone classes. Table 3.10 contains the results.

Table 3.10 Benefits ($) per Street Tree by 1990 USDA Plant Hardiness Zone classes

Benefits per Street Tree ($)	Zones 3 + 4 (n = 21)	Zone 5 (n = 58)	Zone 6 (n = 24)	Zone 7 (n = 20)
Mean	140.73	131.98	133.82	131.45
Median	138.55	133.29	130.72	135.14
StdDev	23.82	26.04	22.42	20.11
StdErr	5.20	3.42	4.58	4.50
UCL (α =.10)	149.28	137.61	141.35	138.85
LCL (α =.10)	132.18	126.36	126.29	124.05

No significant difference ($\alpha = .10$) was found in a comparison of means of benefits per street tree for each 1990 USDA Plant Hardiness Zone class. Benefits per street tree and population density were found to be weakly correlated (-0.14) for all 123 municipalities. Means for each zone class were weighted in a manner similar to genus and species composition (i.e. by the relative percentage of summed street length expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places within that zone class – see Table 3.1). The weighted mean of benefits per street tree statewide was found to be 133.16, nearly equivalent to the unweighted mean of 133.75.

Next, for each municipality where tree species and DBH data was available and the inventoried summed street length of streets expected to contain street trees could be determined, i-Tree Streets was used to calculate total annual benefits (energy conservation, air quality improvement, CO_2 reduction, stormwater control, and property value increase) provided by street trees in that municipality. Total annual benefits (in dollars) were then divided by summed street length (meters) of streets expected to contain street trees for each municipality to create a metric of street tree benefits per meter per municipality. Figure 3.7 illustrates the methodology for creating this metric. Results are shown in Table 3.11. A metric for benefits per mile has also been calculated.

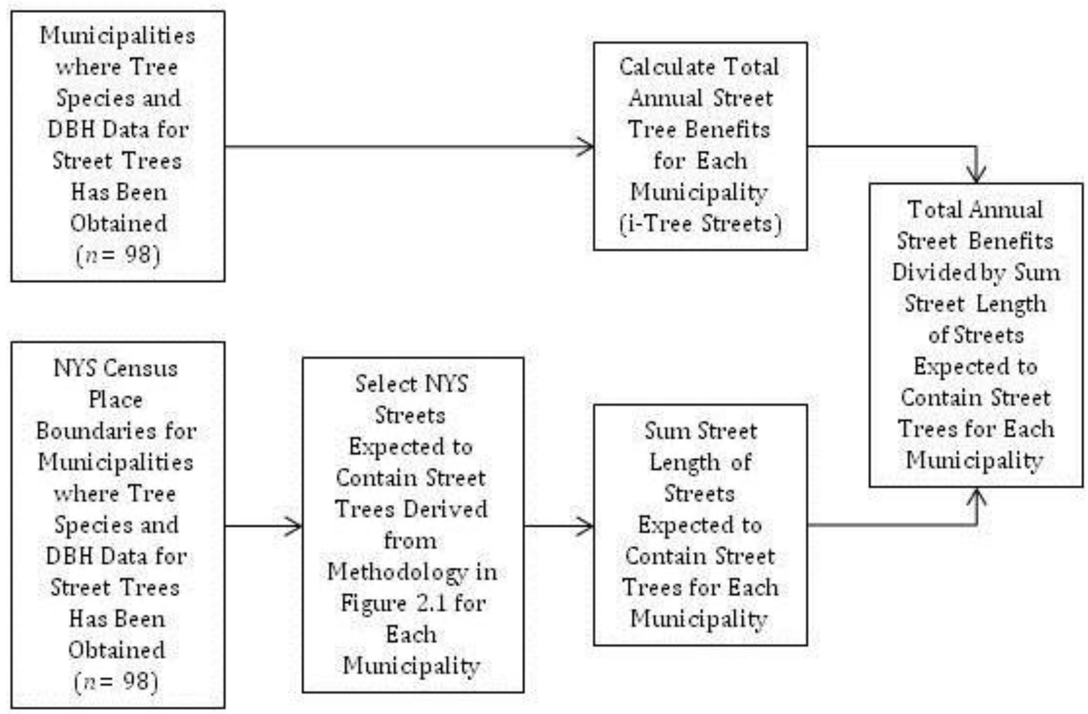


Figure 3.9 Methodology for creating street tree benefits per meter metric for municipalities in New York State where tree species and DBH data was available and i-Tree Streets was used to calculate total annual benefits

Table 3.11 Benefits ($) by street length for streets expected to contain street trees

n = 98	Benefits per Meter	Benefits per Mile
Mean	5.20	8365.77
Median	4.74	7630.39
StdDev	3.13	5034.46
StdErr	0.32	508.56
UCL (α =.10)	5.72	9202.35
LCL (α =.10)	4.68	7529.19

Results for benefits by street length were analyzed further to explore variability by 1990 USDA Plant Hardiness Zone class. Results of the one way analysis of variance (ANOVA) for benefits per mile by 1990 USDA Plant Hardiness Zone class are contained in Table 3.12 (α = .10, r^2 = 0.23, F < .0001).

Table 3.12 One way analysis of variance (ANOVA) for Benefits ($) per mile by 1990 USDA Plant Hardiness Zone class

USDA Zone Class	Mean	Std Error	90% LCL	90% UCL
3 + 4 (*n* = 19)	7382.86	1029.88	5672.00	9093.72
5 (*n* = 45)	6702.38	669.20	5590.68	7814.07
6 (*n* = 21)	9388.16	979.61	7760.81	11015.50
7 (*n* = 13)	13908.67	1245.06	11840.30	15977.00

Results contained in Table 3.12, confirmed by a statistical comparison of means, indicate significant differences in benefits between Zone 7 and all other zones, and between Zone 6 and Zone 5. Benefits per mile increased with higher minimum temperatures and benefits per mile for inventories in Zone 7 were found to be significantly higher than benefits per mile in all other zones. The reasons for these results are not immediately clear, but, as with benefits per street tree, population density is weakly correlated with benefits per mile (0.19) and does not appear to be an explanatory factor.

Street Tree Numbers

Although a case has been made that metrics based on street tree benefits are preferable to metrics based on street tree counts for evaluating street trees within and between municipalities, estimation of street tree numbers by municipality and statewide is still a useful endeavor. For example, if both street tree numbers and the percentages of street tree genera can be estimated by municipality and statewide, then the number of street trees in a particular genus can be estimated in the model construct shown in Figure 3.8.

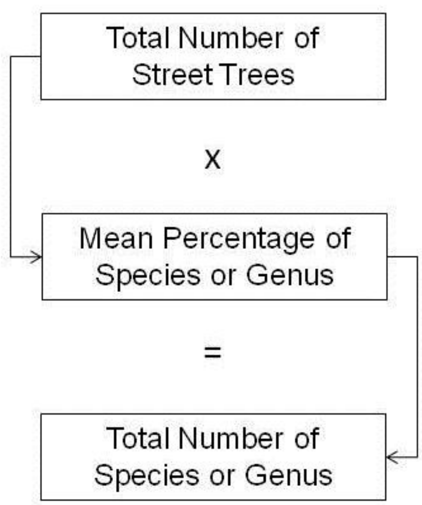


Figure 3.10 Model construct: Street Tree Numbers for Prevalent Street Tree Species and Genera by Municipality and Statewide

Given the threat posed by the Emerald Ash Borer (EAB) to all *Fraxinus* (ash) trees and the threat posed by the Asian Longhorned Beetle (ALB) to many hardwood tree genera including all Acer (maple) trees, estimating the number of street trees in a particular genus could be helpful in understanding the scope of the threat posed by an invasive pest species, budgeting for potential tree removals, etc.

To estimate street tree numbers by municipality and statewide, a similar methodology to the one shown in Figure 3.7 was used to create a metric for street trees per meter (i.e. the number of street trees in each municipality divided by the summed length of streets expected to contain street trees for each municipality) for inventoried municipalities where street tree numbers and summed street length of streets expected to contain street trees could be determined. Preliminary results (i.e. unweighted means) are shown in Table 3.13. A metric for street trees per mile has also been calculated.

Table 3.13 Street trees by street length for streets expected to contain street trees in New York State (unweighted)

n = 127	Street Trees per Meter	Street Trees per Mile
Mean	0.042	67.00
Median	0.035	56.93
StdDev	0.025	40.87
StdErr	0.002	3.63
UCL (α =.10)	0.045	72.97
LCL (α =.10)	0.038	61.03

Results for trees by street length were analyzed further to explore variability by 1990 USDA Plant Hardiness Zone class. Statistics for street tree numbers per meter of street length and street tree numbers per mile of street length by 1990 USDA Plant Hardiness Zone class were calculated and are contained in Table 3.14.

Table 3.14 Street trees by street length for streets expected to contain street trees in New York State by 1990 USDA Plant Hardiness Zone Class

	Trees / Meter Zones 3 + 4	Trees / Meter Zone 5	Trees / Meter Zone 6	Trees / Meter Zone 7
Mean	0.029	0.032	0.049	0.071
Std Dev	0.019	0.017	0.018	0.029
Count	30	49	25	23
Std Err	0.003	0.002	0.004	0.006
90% UCL	0.034	0.036	0.055	0.081
90% LCL	0.023	0.028	0.043	0.061

	Trees / Mile Zones 3 + 4	Trees / Mile Zone 5	Trees / Mile Zone 6	Trees / Mile Zone 7
Mean	45.90	52.01	78.25	114.24
Std Dev	30.50	27.42	29.41	46.62
Count	30	49	25	23
Std Err	5.57	3.92	5.88	9.72
90% UCL	55.06	58.45	87.92	130.23
90% LCL	36.74	45.56	68.57	98.25

Statistics in Table 3.14 suggest meaningful differences in street tree numbers by street length for 1990 USDA Plant Hardiness Zone classes. These differences were assessed for statistical significance in a one way analysis of variance (ANOVA) for street trees per street length (miles) by 1990 USDA Plant Hardiness Zone class. Results were found to be statistically significant (α = .10, r^2 = 0.37, F < .0001) and are contained in Table 3.15.

Table 3.15 One way analysis of variance (ANOVA) for number of street trees per mile by 1990 USDA Plant Hardiness Zone class

USDA Zone Class	Mean	Std Error	90% LCL	90% UCL
3 + 4 (*n* = 30)	45.90	5.97	36.00	65.60
5 (*n* = 49)	52.01	4.67	44.26	59.75
6 (*n* = 25)	78.25	6.54	67.40	89.09
7 (*n* = 23)	114.24	6.82	102.94	125.55

Statistically significant differences were found in street tree numbers between most, although not all, 1990 USDA Plant Hardiness Zone classes. For example, significant differences were not found between Zones 3 + 4 and Zone 5, but significant differences were found between Zones 3 + 4 and Zone 6, Zones 3 + 4 and Zone 7, Zone 5 and Zone 6, Zone 5 and Zone 7, and Zone 6 and Zone 7. These results are consistent with results for benefits per mile by 1990 USDA Plant Hardiness Zone class contained in Table 3.12. They also suggest that statewide summary statistics for street tree numbers per meter and per mile should be weighted, similar to statistics for prevalent street tree species and genera, by the relative percentage of summed street length contained within each zone class. For example, to determine statewide summary statistics for street tree numbers per meter and per mile the means for street trees per meter and street trees per mile in each zone class would be weighted by the relative percentage of summed street length contained within each zone class according to the formula:

$$((w1 * m1) + (w2 * m2) + (w3 * m3) + (w4 * m4)) / (w1 + w2 + w3 + w4)$$

Where $m1$, $m2$, $m3$, and $m4$ denote the group means for street trees per meter or street trees per mile (i.e. the mean for 1990 USDA Plant Hardiness Zone classes 3 + 4, 5, 6, and 7) and $w1$, $w2$, $w3$, and $w4$ denote the different weights for each group (i.e. percentages of summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places for 1990 USDA Plant Hardiness Zone classes in New York State) as stated in Table 3.1.

Weighted statewide statistics for street tree numbers per meter of street length and street tree numbers per mile of street length were calculated and compared to unweighted statistics. Results are contained in Table 3.16. Weighted means per meter and per mile represent meaningful increases relative to unweighted means. However, based on statistically significant differences found for street numbers and street length by 1990 USDA Plant Hardiness Zone classes, these weighted means should be judged the more reliable and accurate statistics and will be used in subsequent calculations.

Table 3.16 Street trees by street length for streets expected to contain street trees in New York State (weighted and unweighted means)

New York State	Weighted Mean	Unweighted Mean
Street Trees per Meter	0.050	0.042
Street Trees per Mile	80.47	67.00

CHAPTER 4

STATISTICAL MODEL

Data obtained from municipalities (e.g. cities, villages, CDPs) in New York State possessing a street tree inventory comprise a sample of the statewide population of street trees. Summary statistics of this sample data are helpful in suggesting inferences for the statewide population as a whole, including municipalities in New York State that do not possess a street tree inventory. They provide the basis for a statistical model to make reliable and valid estimates for street trees on a statewide basis. Objectives of the model include calculation of street tree numbers statewide for prevalent tree species and genera and calculation of annual benefits statewide provided by street trees. It has been affirmed previously that statewide calculations should account for statistically significant differences found by 1990 USDA Plant Hardiness Zone classes for (1) mean percentages of prevalent street tree species and genera and (2) means for street trees per meter and street trees per mile of streets expected to contain street trees. Stratifying data and weighting means by 1990 USDA Plant Hardiness Zone class was predicated on the hypothesis that street tree populations vary significantly due to minimum winter temperatures affecting plant hardiness. The validity of this hypothesis will be assessed below and whether additional variables should be included in the statistical model to facilitate its objectives. However, it should be noted that stratifying data and weighting means by 1990 USDA Plant

Hardiness Zone class may not only reflect significant differences based on plant hardiness, but might also capture significant effects for other criteria such as development intensity. In that light, not only will the validity of stratifying data and weighting means by 1990 USDA Plant Hardiness Zone class be assessed, but additional environmental and social factors will be explored and tested for statistical significance in calculating street tree numbers statewide for prevalent tree species and genera and the annual benefits statewide provided by street trees

Minimum Temperature

It was affirmed in deriving summary statistics from sample street inventory data that consideration should be given to minimum winter temperature and plant hardiness in explaining variability in street tree populations and in particular tree species and genus composition. Minimum winter temperature is frequently employed as a variable in assessing plant geography. For example, the Sunset Publishing Corporation (2011) evaluates “winter lows” in mapping gardening climate zones and mean January temperature is one of thirty-eight environmental variables used by the United States Forest Service (2007) to predict habitat for common tree species in forests in the Eastern United States. To investigate an effect on New York State street trees due to minimum temperature, municipalities in New York State (e.g. cities, villages, CDPs) were referenced to the 1990 USDA Plant Hardiness Zone Map (US

National Arboretum 1990). Each municipality was selected into one of five plant hardiness zones (Zone 3, Zone 4, Zone 5, Zone 6, or Zone 7) according to a methodology illustrated in Figure 2.2. Municipalities located in Zones 3 and 4 were grouped into one zone class and four zone classes were used to explore differences in sample street inventory data due to minimum temperature. Summary statistics suggested effects based on zone class for prevalence of street tree species and genera, species diversity, benefits provided by street trees, and street tree numbers.

To test the statistical significance of zone class effects for prevalence of street tree species and genera, one way analysis of variance (ANOVA) and rank sum Kruskal-Wallis analyses were conducted to compare differences between the means of prevalent street tree genera and species inventory percentages by 1990 USDA Plant Hardiness Zone class. Both ANOVA and Kruskal-Wallis analyses were conducted because ANOVA assumes that data is normally distributed and some sample data was found not to be normally distributed. For example, *Acer platanoides* data was found to be normally distributed for Zone 5 (n = 57) and for Zone 6 (n = 29), but was found not to be normally distributed for Zones 3 + 4 (n = 28) or Zone 7 (n = 18). Data transformations such as taking the log of a distribution were successful in some but not all cases in normalizing non-normal data. Therefore, a Kruskal-Wallis analysis, which is non-parametric and does not assume data is normally distributed, was run in addition to ANOVA.

For genera, results indicate statistically significant effects (α = .10) for *Acer*, *Quercus*, *Platanus*, *Pyrus*, *Fraxinus*, *Picea*, *Prunus*, and *Malus* meaning these street tree genera vary significantly between 1990 USDA Plant Hardiness Zone classes. Results did not indicate statistically significant effects for *Gleditsia*, *Tilia*, *Pinus*, *Ulmus*, and *Robinia* meaning these street tree genera do not vary significantly between 1990 USDA Plant Hardiness Zone classes. For species, results indicate statistically significant effects (α = .10) for *Acer platanoides*, *Acer saccharum*, *Platanus x acerifolia, Pyrus calleryana*, *Quercus palustris*, *Malus species*, and *Picea abies* meaning these street tree species vary significantly between 1990 USDA Plant Hardiness Zone classes. Results did not indicate statistically significant effects for *Acer saccharinum*, *Acer rubrum*, *Gleditsia triacanthos*, *Tilia cordata*, *Fraxinus pennsylvanica*, *Quercus rubra*, *Pinus strobus*, and *Robinia pseudoacacia* meaning these street tree genera do not vary significantly between 1990 USDA Plant Hardiness Zone classes. Eight of the ten most prevalent genera were found to have statistically significant effects for zone class and six of the ten most prevalent species were found to have statistically significant effects for zone class.

Results for species diversity, street tree benefits per mile, and street tree numbers per mile were mixed. For species diversity, effects were found in both ANOVA and Kruskal-Wallis analyses for the Shannon-Weiner Diversity Index whereby the mean value for Zone 7 was significantly greater than the mean values for the other zone classes. Similarly, after the log of the inverse of Simpson's Diversity Index was taken to normalize data, effects were found in both ANOVA and Kruskal-Wallis analyses for the inverse of Simpson's Diversity Index whereby the mean value for Zone 7 differed significantly from the mean values for the other zone classes. In other words, species diversity for Zone 7 was found to be significantly greater than species diversity for Zones 3 + 4, Zone 5, and Zone 6. This effect would appear to be due in part to fewer maples being planted as street trees in Zone 7 relative to the other zone classes. For street tree benefits per mile, although summary statistics indicated that benefits per mile increased with higher minimum temperatures, a statistically significant effect for zone class was not found in either ANOVA or Kruskal-Wallis analyses. For street tree numbers per mile, a Kruskal-Wallis analysis found a statistically significant effect for zone class with street tree numbers per mile increasing from Zones 3 + 4 to Zone 7; an ANOVA analysis indicated a similar effect but, because data could not be normalized, statistical significance of an effect for zone class is predicated on the Kruskal-Wallis analysis.

Although results above do not uniformly show statistically significant effects for zone class, it does appear that the 1990 USDA Plant Hardiness Zone class is a useful predictor for modeling species and genus prevalence, species diversity, and street tree numbers per mile statewide. An assumption has been made that effects indicated by 1990 USDA Plant Hardiness Zone classes reflect minimum winter temperature. It is also possible, however, that these zones could vary by additional characteristics. For example, Zone 7, which encompasses New York City, southern Westchester County, and much of Long Island, is more densely populated and intensely developed than other zone classes in New York State. It has already been reported that species diversity, street tree benefits per tree, and street tree benefits per street mile are weakly correlated with population density and that population density does not appear to have much explanatory power with regard to these measures. Potential effects attributable to development intensity and additional factors, both singularly and in conjunction with 1990 USDA Plant Hardiness Zone classes, will be assessed in detail below.

Additional Climatic Variables

As cited previously, the United States Forest Service (2007) uses mean January temperature as one of thirty-eight environmental variables to predict habitat for common tree species in eastern United States forests. A list of the thirty-eight variables, which include variables for elevation, soils, and land use, is contained in Table 4.1. The Sunset Publishing Corporation, which publishes Sunset Magazine and Sunset Western Gardener, has created its own map of climate zones based not only on “winter lows,” but also on distance from the equator, elevation, ocean influence, continental air mass influence, mountains and hills, and local terrain (2011).

Table 4.1 Environmental variables used by the United States Forest Service to predict tree species habitat for forests in the Eastern United States

Climate	
TAVG:	Mean annual temperature (°C)
TJAN:	Mean January temperature (°C)
TJUL:	Mean July temperature (°C)
TMAYSEP:	Mean May-September temperature (°C)
PPT:	Annual precipitation (mm)
PPTMAYSEP:	Mean May-September precipitation (mm)
JULJANDIFF:	Mean difference between July and January Temperature (°C)
Elevation	
ELV_CV:	Elevation coefficient of variation
ELV_MAX:	Maximum elevation (m)
ELV_MEAN:	Average elevation (m)
ELV_MIN:	Minimum elevation (m)
ELV_RANGE:	Range of elevation (m)
Soil Class	
ALFISOL:	Alfisol (%)
ARIDISOL:	Aridisol (%)
ENTISOL:	Entisol (%)
HISTOSOL:	Histosol (%)
INCEPTSOL:	Inceptisol (%)
MOLLISOL:	Mollisol (%)
SPODOSOL:	Spodosol (%)
ULTISOL:	Ultisol (%)
VERTISOL:	Vertisol (%)
Soil Property	
BD:	Soil bulk density (g/cm3)
CLAY:	Percent clay (< 0.002 mm size)
KFFACT:	Soil erodibility factor, rock fragment free (susceptibility of soil erosion to water movement)
NO10:	Percent soil passing sieve No. 10 (coarse)
NO200:	Percent soil passing sieve No. 200 (fine)
OM:	Organic matter content (% by weight)
ORD:	Potential soil productivity (m3 of timber/ha)
PERM:	Soil permeability rate (cm/hr)
PH:	Soil pH
ROCKDEP:	Depth to bedrock (cm)
SLOPE:	Soil slope (%) of a soil component
TAWC:	Total available water capacity (cm, to 152 cm)
Land Use and Fragmentation	
FRAG:	Fragmentation Index (Riitters et al. 2002)
AGRICULT:	Cropland (%)
FOREST:	Forest land (%)
NONFOREST:	Nonforest land (%)
WATER:	Water (%)

Minimum winter temperature as referenced by 1990 USDA Plant Hardiness Zones has been hypothesized as an explanatory variable for street tree populations in New York State and the statistically significant effects reported above suggest strongly that it would be a useful predictor for modeling street trees statewide. It is possible, however, that additional climatic and environmental variables, including some used by the United States Forest Service to predict habitat for common tree species in eastern United States forests and by Sunset Western Garden to map gardening climate zones, could be helpful in explaining variability in New York State street tree populations and in generating reliable and valid estimates for street trees on a statewide basis. At the same time, models that apply to forest habitat and gardening climate zones are unlikely to be directly analogous to street trees since street trees are not randomly distributed, but have been planted intentionally. In addition, urban environmental conditions differ in many respects from environmental conditions found in forests. For example, Craul and Klein (1980) found that streetside soils in Syracuse, NY had higher bulk density, pH, specific conductance, and weight loss on ignition and lower air-filled pore space and available water than native soils. The urban heat island effect, whereby buildings and streets release at night solar heat absorbed during the day, has also increased minimum temperatures in cities relative to rural environments (Kalnay & Cai 2003). Finally, most variables used in forest habitat modeling, which is based on Forest Inventory Analysis (FIA) field data, are typically not collected in street tree inventories, making extension of forest habitat modeling to street tree population modeling limited in most respects.

To assess whether climatic and environmental variables in addition to minimum winter temperature could be helpful in explaining variability in New York State street tree populations and in generating reliable and valid estimates for street trees on a statewide basis, the following data was gathered for municipalities in New York for which street tree inventory data has been obtained: annual precipitation, elevation, and distance from the equator. Data for annual precipitation was obtained from the PRISM (Parameter-elevation Regressions on Independent Slopes Model) Climate Group, Oregon State University (2007); this data consists of geographic areas computed from thirty year normals (i.e. the arithmetic mean of values over a thirty year period) used by the National Climatic Data Center (NCDC) to measure climate data. Data for elevation and distance from the equator was obtained from the Geographic Names Information System (GNIS) of the United States Geological Survey (USGS 2011); elevation data is based on the elevation of the GNIS determined centroid (i.e. geographic center point) for each New York State municipality and distance from the equator was computed from the latitude and longitude coordinates of all centroids.

Data for soils and bedrock geology were also considered for assessment. STATSGO (State Soil Geographic) soils data (e.g. pH, available water capacity, and bulk density) was obtained from the National Resources Conservation Service (NRCS). Bedrock geology data (e.g. dominant and secondary lithology) was obtained from the New York State Geological Survey via the New York State Museum. These data were then mapped in relation to municipal boundaries from which street tree inventory data had been obtained. This mapping found a complete or partial lack of soils data for many New York State municipalities including many cities statewide and most municipalities in Zone 7 (i.e. New York City, southern Westchester County, and much of Long Island). For municipalities where soils data was available, multiple soil classes were found within municipal boundaries, thereby requiring individual trees to be geo-referenced (i.e. mapped with latitude and longitude coordinates) in order to be correlated accurately to soils data. The need for geo-referenced trees applies as well to the bedrock geology data. Because many street tree inventory datasets are not geo-referenced, the number of datasets that could be included in analyzing relationships between street tree populations on the one hand and soils and bedrock geology data on the other would be reduced meaningfully. Given this reduced sample size, coupled with the finding made by Craul and Klein (1980) that streetside soils differ significantly from native soils, a judgment was made that analyzing relationships between street tree populations and soils and bedrock geology data is beyond the scope of this research and these data were omitted in assessing variability in New York State street tree populations.

Linear regressions were run in which mean inventory percentages for prevalent species and genera by 1990 USDA Plant Hardiness Zone class were regressed with annual precipitation, elevation, and distance from the equator. Prevalent species and genera rather than street trees per mile were selected as dependent variables since there is no evidence in peer reviewed scientific literature to suggest that the number of street trees in a municipality is influenced by climatic and environmental factors. However, there is evidence in this literature that climatic and environmental factors influence tree species composition in urban and natural forests (Goldblum 2010, Yang 2009, Iverson et al 2004). Regression results found statistically significant effects (α =.10) for many, but not all prevalent street tree species and genera for annual precipitation, elevation, and distance from the equator. Distance from the equator explained more variability than annual precipitation and elevation, and annual precipitation explained more variability than elevation. However, when included in ANCOVA (Analysis of Co-variance) models with 1990 USDA Plant Hardiness Zone classes, zone class was found a better predictor of street tree species and genera than either annual precipitation, elevation, or distance from the equator. In addition, variance inflation factor (VIF) values, a measure of multi-collinearity between variables in a model, were consistently and significantly larger for distance from the equator and elevation with zone class than VIF values for annual precipitation with zone class. Therefore, annual precipitation appears a better candidate than distance from the equator or elevation for inclusion in a model with zone class.

Land Use

Studies correlating urban trees with urban land use have typically targeted tree canopy cover rather than street tree inventory data including population characteristics such as species and genus composition. Moreover, most correlations between tree canopy cover and land use have focused on canopy cover for the entire urban forest rather than on canopy cover for street trees. For example, Sanders and Stevens (1984) found for Dayton, OH that single family residential land use had the highest percentage of tree canopy cover compared to all other land uses; Rowntree (1984) found in a comparison of four cities (Birmingham, AL, Cincinnati, OH, Dayton, OH, and Syracuse, NY) that 50 to 60% of available growing space in residential areas was occupied by tree canopy; Nowak et al (1996) found for fifty-eight cities in the United States that park and residential land use had the greatest percentage of tree canopy cover compared to other land uses; and Heynen and Lindsey (2003) found for sixty urban areas in Central Indiana that increased urban tree canopy cover was associated with counties that already had more canopy cover. Fewer studies have correlated street tree canopy cover with land use. Maco and McPherson (2002) found for Davis, CA increased street tree canopy cover in older city-center neighborhoods, and Porcasky and Banis (2005) found in Portland, OR that residential areas had more canopy cover than commercial/industrial areas and street trees contributed a greater percentage of canopy cover in commercial/industrial areas than in residential areas.

Land use correlations with urban forest tree canopy cover should not be assumed to translate directly into land use correlations with either street tree canopy cover or street tree population characteristics. Nevertheless, the preponderance of findings from the studies above suggests there may be an effect for land use type on street tree populations and, more specifically, an effect predicated on residential land use versus commercial or industrial land use. Such an effect would be consistent with the sample street tree inventory methodology delineated by Jaenson et al (1992) in which street tree populations were assumed to vary sufficiently by land use type that a sample stratified by at least three land use types – rectilinear residential (older neighborhoods with gridded streets, sidewalks, and treelawns), curvilinear residential (newer neighborhoods with cul-de-sacs), and downtown (central business district) – is required. Although results from sample street tree inventories in four New York State cities were deemed sufficiently accurate (within ± 10%) in estimating street tree numbers and species composition when checked against existing complete or partial inventories, the assumption that street tree populations vary by land use type was not specifically tested.

Correlating land use with street tree populations is complicated further by infrequent collection of land use data associated with individual street trees in street tree inventories. In addition, when land use data is collected in street tree inventories, data classes are often not standardized making the union of data from multiple inventories difficult. Finally, associating street tree data post-inventory with land use classifications from adjacent tax parcels can be problematic since land use at parcel scale is commonly subject to change and may not be accurate. For example, Lu et al (2010) found in a study of street tree mortality in New York City that 48% of tax parcel land use classifications associated with planting locations by the New York City Department of City Planning were inaccurate and locations had to be field-verified for their correct land use class. In addition, associating street tree data post-inventory with land use classifications from adjacent tax parcels requires accurately referencing each street tree location with latitude and longitude coordinates, whether collected with GPS (Global Positioning System) equipment in an inventory or geocoded (i.e. converted to latitude and longitude coordinates) from a street address. However, latitude and longitude coordinates for tree locations are often not collected in an inventory while street addresses are not always sufficiently accurate to satisfy the requirements of geocoding software.

Notwithstanding these issues, the following methodology was employed to assess land use correlations with street tree populations in New York State. Land use land cover (LULC) data was obtained from the 2006 National Land Cover Dataset (NLCD) generated by the Multi-Resolution Land Characteristics (MRLC) Consortium, a group of nine United States government agencies (United States Geological Survey, United States Environmental Protection Agency, United States Forest Service, National Oceanic and Atmospheric

Administration, National Aeronautics and Space Administration, Bureau of Land Management, National Park Service, National Resources Conservation Service, and United States Fish and Wildlife Service). NLCD data is collected in 30 meter by 30 meter gridded cells for the entire United States and differentiated into 25 LULC classes (MRLC 2011). Descriptions of the NLCD LULC classes are shown in Table 4.2.

Table 4.2 National Land Cover Dataset (NLCD) land use land cover (LULC) data classes

11 - Open water
12 - Perennial Ice/Snow
21 - Developed, Open Space
22 - Developed, Low Intensity
23 - Developed, Medium Intensity
24 - Developed, High Intensity
31 - Barren Land
32 - Unconsolidated Shore
41 - Deciduous Forest
42 - Evergreen Forest
43 - Mixed Forest
51 - Dwarf Scrub (Alaska only)
52 - Scrub/Shrub
81 - Pasture/Hay
82 - Cultivated Crops
90 - Woody Wetlands
91 - Palustrine Forested Wetland (coastal only)
92 - Palustrine Scrub/Shrub (coastal only)
93 - Estuarine Forested Wetlands (coastal only)
94 - Estuarine Scrub/Shrub (coastal only)
95 - Emergent Herbaceous Wetland
96 - Palustrine Emergent Wetland (Persistent) (coastal only)
97 - Palustrine Emergent Wetland (coastal only)
98 - Palustrine Aquatic Bed (coastal only)
99 - Estuarine Aquatic Bed (coastal only)

Of particular interest are LULC classes 21, 22, 23, and 24 which encompass residential and non-residential development. These classes approximate more closely than other classes Census Places and Census Blocks with population density of at least 500 ppsm, or those geographies where the case has been made been previously that street trees are most likely to be found. Detailed descriptions for these classes are as follows:

21. Developed, Open Space - Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.

22. Developed, Low Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.

23. Developed, Medium Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.

24. Developed, High Intensity - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.

The profile of LULC grid cell distribution within all Census Places in New York State (i.e. cities, villages, and CDPs) was analyzed, both statewide and by 1990 USDA Plant Hardiness Zone classes, according to a methodology illustrated in Figure 4.1. LULC grid cells characterized by development (i.e. LULC classes 21, 22, 23, and 24) were found to comprise 58.88% of all grid cells for all NYS Census Places statewide. Distribution varied geographically with grid cells characterized by development totaling 44.02% in Zones 3 + 4, 45.32% in Zone 5, 67.58% in Zone 6, and 69.35% in Zone 7, reflecting increased intensity of development in southern New York State. Distribution also varied by municipality type with grid cells characterized by development totaling 70.72% for cities, 51.59% for Villages, and 58.03% for CDPs reflecting increased intensity of development in cities relative to villages and CDPs.

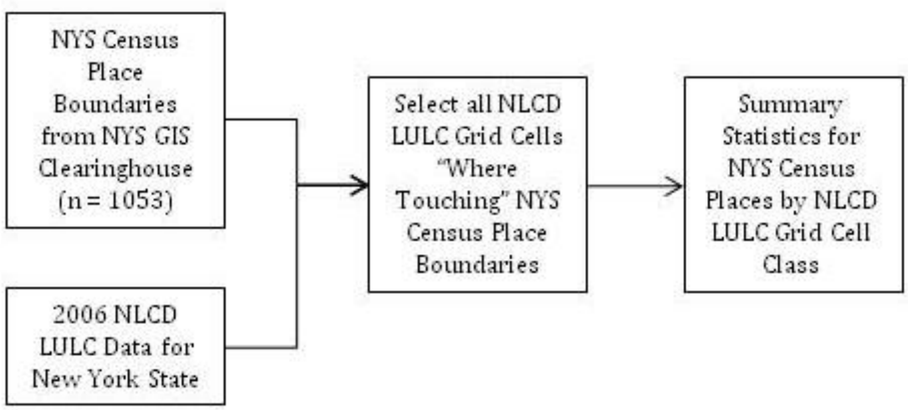


Figure 4.1 Methodology for generating profile of LULC grid cell class distribution within all Census Places in New York State

To assess whether LULC grid cells can be correlated with street tree populations in New York State, and more specifically whether LULC classes 21, 22, 23, and 24 might be helpful in explaining those correlations, street trees in forty-one municipalities with geo-referenced tree locations (i.e. possessing latitude and longitude coordinates) were associated with the LULC grid cell classification of those locations according to a methodology illustrated in Figure 4.2. Results indicate that for these forty-one municipalities, most street trees (94.13% mean, 95.34% median) were associated with LULC grid cell classes 21, 22, 23, and 24. In other words, LULC grid cells characterized by development (i.e. LULC classes 21, 22, 23, and 24) account for the overwhelming majority of streets trees in the forty-one municipalities sampled.

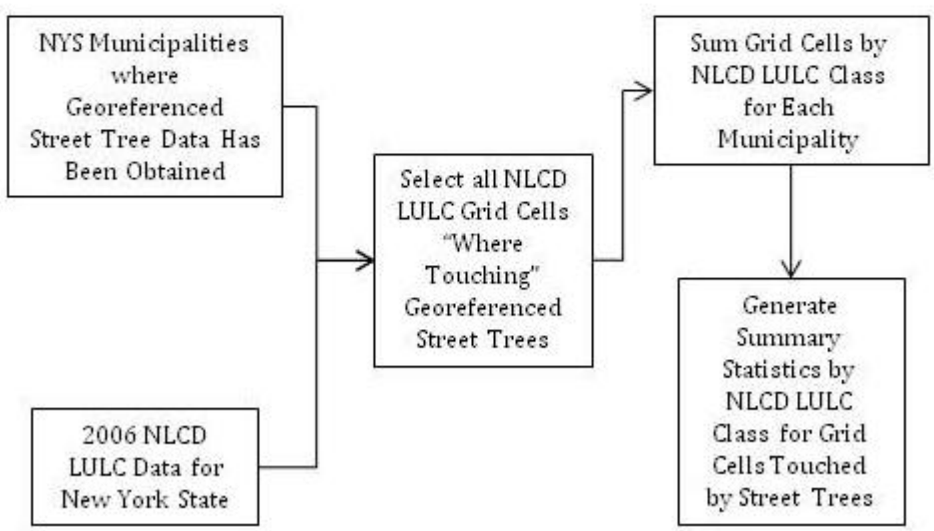


Figure 4.2 Methodology for determining grid cells by class touched by street trees for forty-one municipalities in New York State

While the cumulative percentage of LULC grid cells in classes 21, 22, 23, and 24 associated with street trees was consistent between municipalities, the relative distribution of these four grid cell classes varied meaningfully (i.e. each mean percentage relative to the others): LULC 21 – 24.57%, LULC 22 – 38.65%, LULC 23 – 22.20%, and LULC 24 – 8.72%.

Further examination revealed differences in distribution profiles between cities, villages, and CDPs with cities having smaller percentages of LULC 21 grid cells than villages and CDPs, but greater percentages of LULC 23 and 24 grid cells than villages and CDPs (Figure 4.3). These differences were found to be consistent for all municipalities and also for municipalities with street tree inventories across 1990 USDA Plant Hardiness Zone classes.

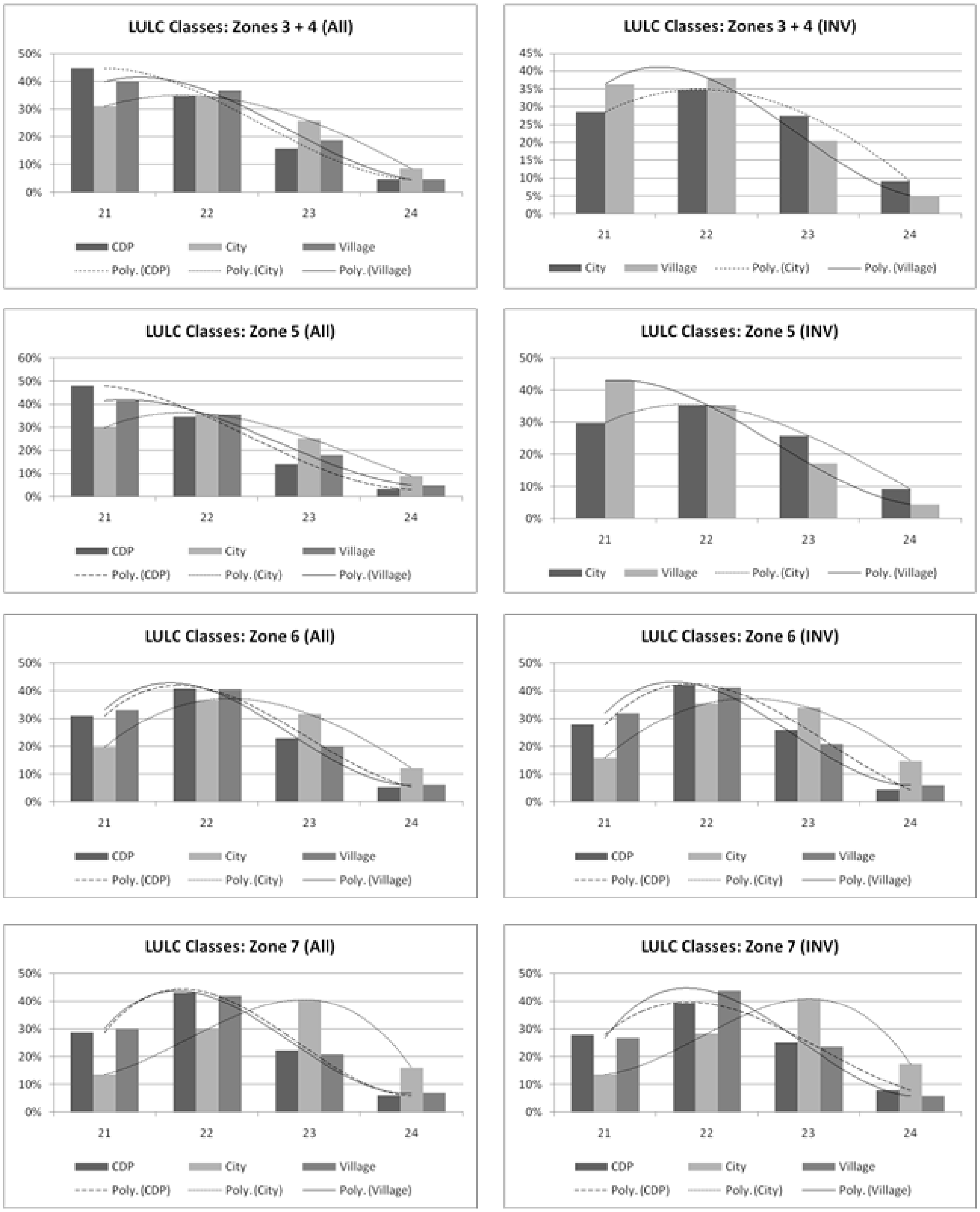


Figure 4.3 LULC grid cell distribution profiles for cities, villages, and CDPS by 1990 USDA Plant Hardiness Zones and municipalities with street tree inventories

The sample of inventoried municipalities was then assessed in relation to all municipalities for LULC grid cell classes 21, 22, 23, and 24 by comparing the relative percentages of these grid cell classes. Statewide results from paired t-tests and Mann–Whitney *U* tests indicated statistically significant differences for grid cells classes 21, 23, and 24 with the sample mean for grid cell class 21 less than the population mean and the sample mean for grid cell classes 23 and 24 greater than the population mean. This suggests that the sample of inventoried municipalities may be biased towards increased intensity of development.

Although results generated by methodologies illustrated in Figures 4.1, 4.2, and 4.3 assess trends in the distribution of LULC grid cell classes and development intensity relative to 1990 USDA Plant Hardiness Zones and municipality types, they do not indicate whether these trends translate into differences in street tree species and genus composition relative to development intensity. To assess whether street tree species and genus composition might vary due to development intensity, prevalent street trees species and genera were associated with LULC grid cell classes 21, 22, 23, and 24 according to a methodology shown in Figure 4.4.

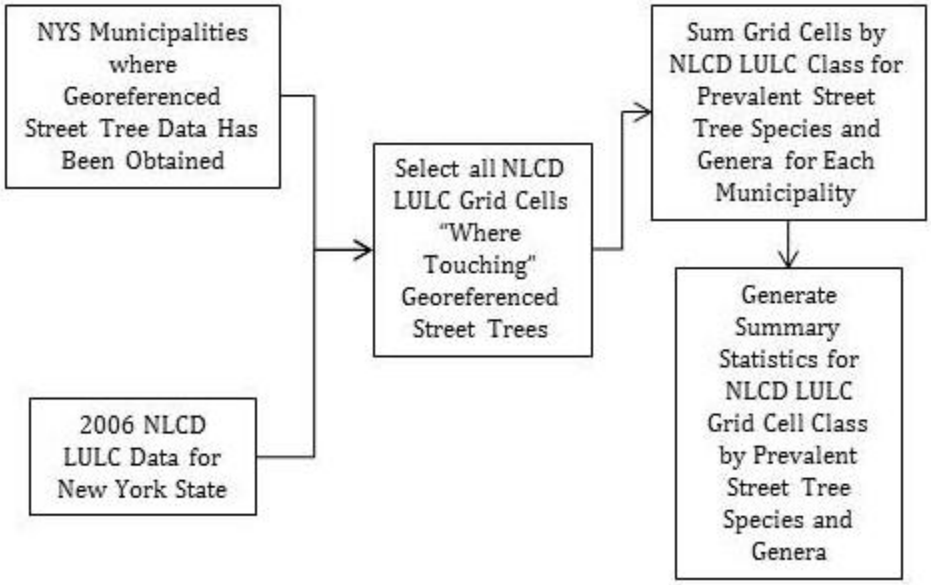
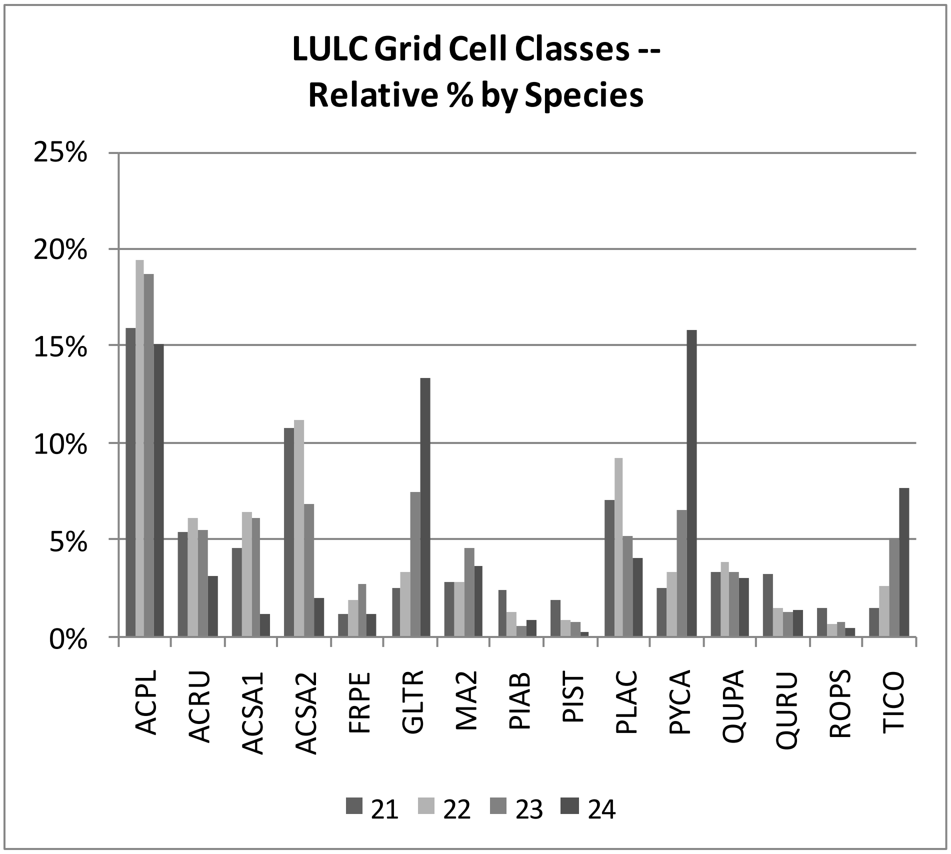


Figure 4.4 Methodology for associating LULC grid cell classes 21, 22, 23, and 24 with prevalent street tree species and genera in New York State

Relative percentages for grid cell classes by prevalent street tree species and genera were calculated for each municipality. These percentages were then averaged and plotted for prevalent species and genera as shown in Figure 4.5 and Figure 4.6. Results suggest effects for several species and genera due to development intensity. For example, percentages of *Acer saccharum* (Sugar Maple) and *Platanus x acerifolia* (London Planetree) decline with development intensity (i.e. percentages decline from LULC grid cell class 21 to LULC grid cell class 24) while percentages of *Gleditsia triacanthos* (Honeylocust) and *Pyrus calleryana* (Callery Pear) increase with development intensity (i.e. percentages increase from LULC grid cell class 21 to LULC grid cell class 24).



ACPL	*Acer platanoides*	PIST	*Pinus strobus*
ACRU	*Acer rubrum*	PLAC	*Platanus x acerifolia*
ACSA1	*Acer saccharinum*	PYCA	*Pyrus calleryana*
ACSA2	*Acer saccharum*	QUPA	*Quercus palustris*
FRPE	*Fraxinus pennsylvanica*	QURU	*Quercus rubrum*
GLTR	*Gleditsia triacanthos*	ROPS	*Robinia pseudoacacia*
MA2	*Malus species*	TICO	*Tilia cordata*
PIAB	*Picea abies*		

Figure 4.5 Relative percentages of LULC grid cell classes characterized by development (21, 22, 23, and 24) by prevalent street tree species

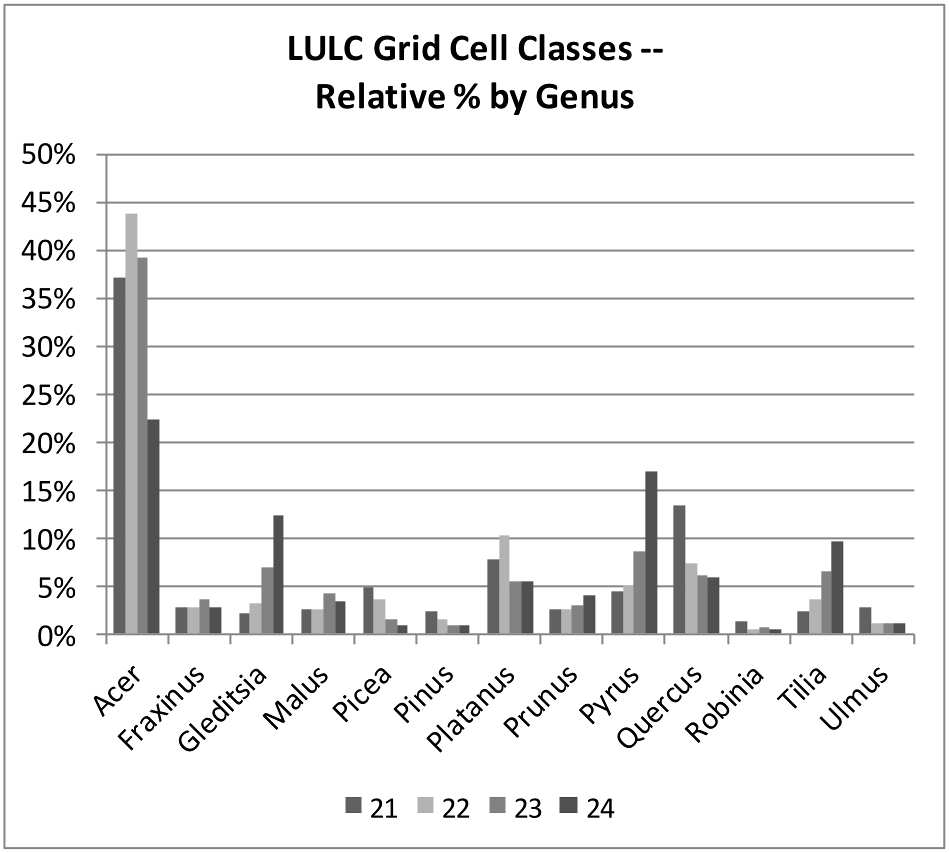
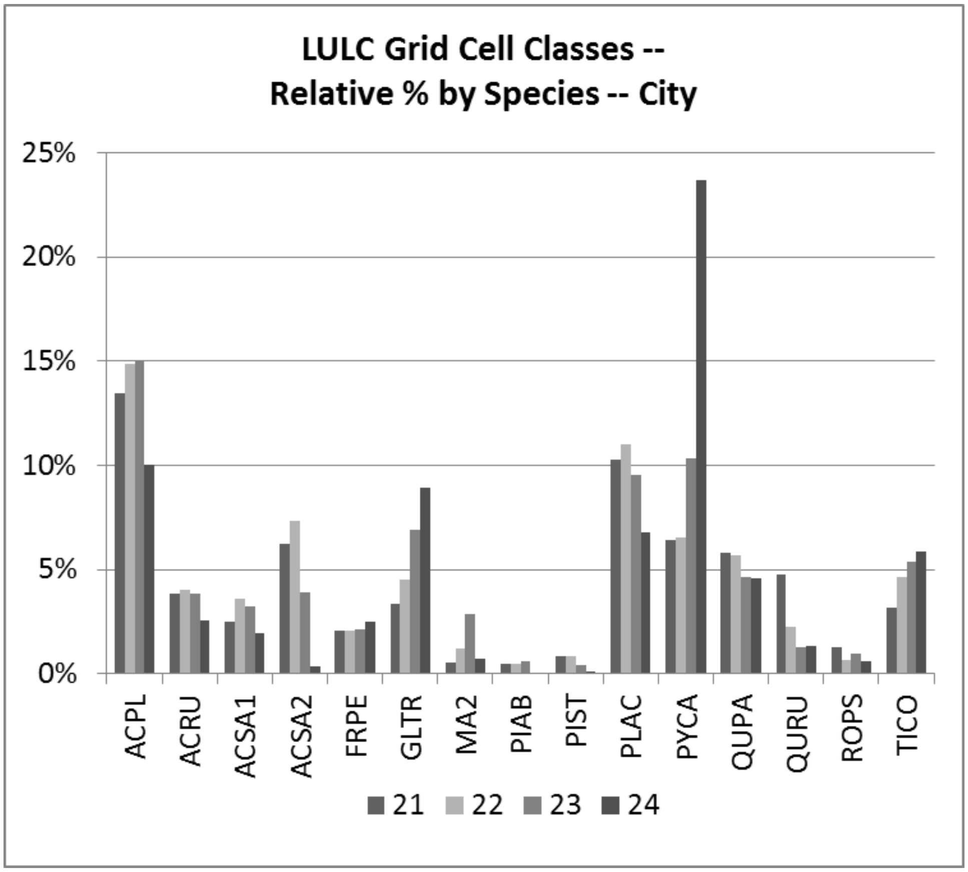


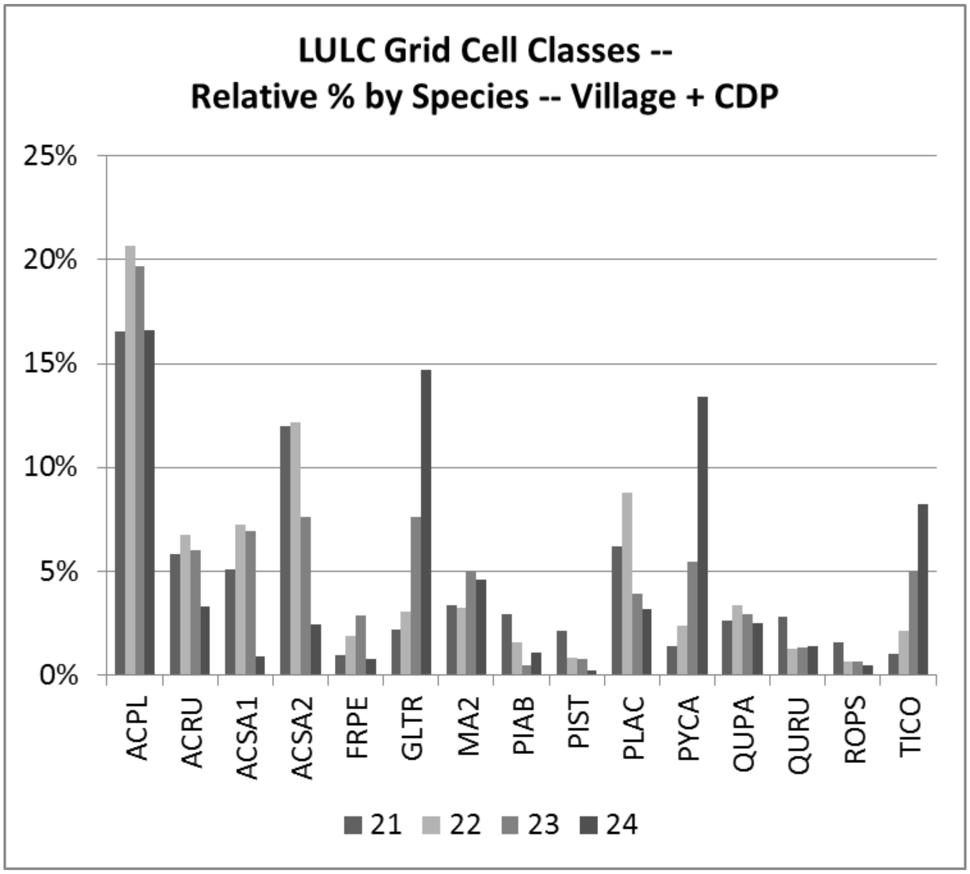
Figure 4.6 Relative percentages of LULC grid cell classes characterized by development (21, 22, 23, and 24) by prevalent street tree genera

These effects are seen as well when cities are analyzed separately from villages and CDPs. Percentages for some species and genera vary meaningfully by municipality type (Figures 4.7, 4.8, 4.9, 4.10). For example, percentages of *Pyrus calleryana* (Callery Pear) are greater for cities than for villages and CDPs, but percentages of *Gleditsia triacanthos* (Honeylocust) are greater for villages and CDPs than for cities.



ACPL	*Acer platanoides*	PIST	*Pinus strobus*
ACRU	*Acer rubrum*	PLAC	*Platanus x acerifolia*
ACSA1	*Acer saccharinum*	PYCA	*Pyrus calleryana*
ACSA2	*Acer saccharum*	QUPA	*Quercus palustris*
FRPE	*Fraxinus pennsylvanica*	QURU	*Quercus rubrum*
GLTR	*Gleditsia triacanthos*	ROPS	*Robinia pseudoacacia*
MA2	*Malus species*	TICO	*Tilia cordata*
PIAB	*Picea abies*		

Figure 4.7 Relative percentages of LULC grid cell classes characterized by development (21, 22, 23, and 24) by prevalent New York State street tree species in New York State cities



ACPL	*Acer platanoides*	PIST	*Pinus strobus*
ACRU	*Acer rubrum*	PLAC	*Platanus x acerifolia*
ACSA1	*Acer saccharinum*	PYCA	*Pyrus calleryana*
ACSA2	*Acer saccharum*	QUPA	*Quercus palustris*
FRPE	*Fraxinus pennsylvanica*	QURU	*Quercus rubrum*
GLTR	*Gleditsia triacanthos*	ROPS	*Robinia pseudoacacia*
MA2	*Malus species*	TICO	*Tilia cordata*
PIAB	*Picea abies*		

Figure 4.8 Relative percentages of LULC grid cell classes characterized by development (21, 22, 23, and 24) by prevalent New York State street tree species in New York State villages and CDPs

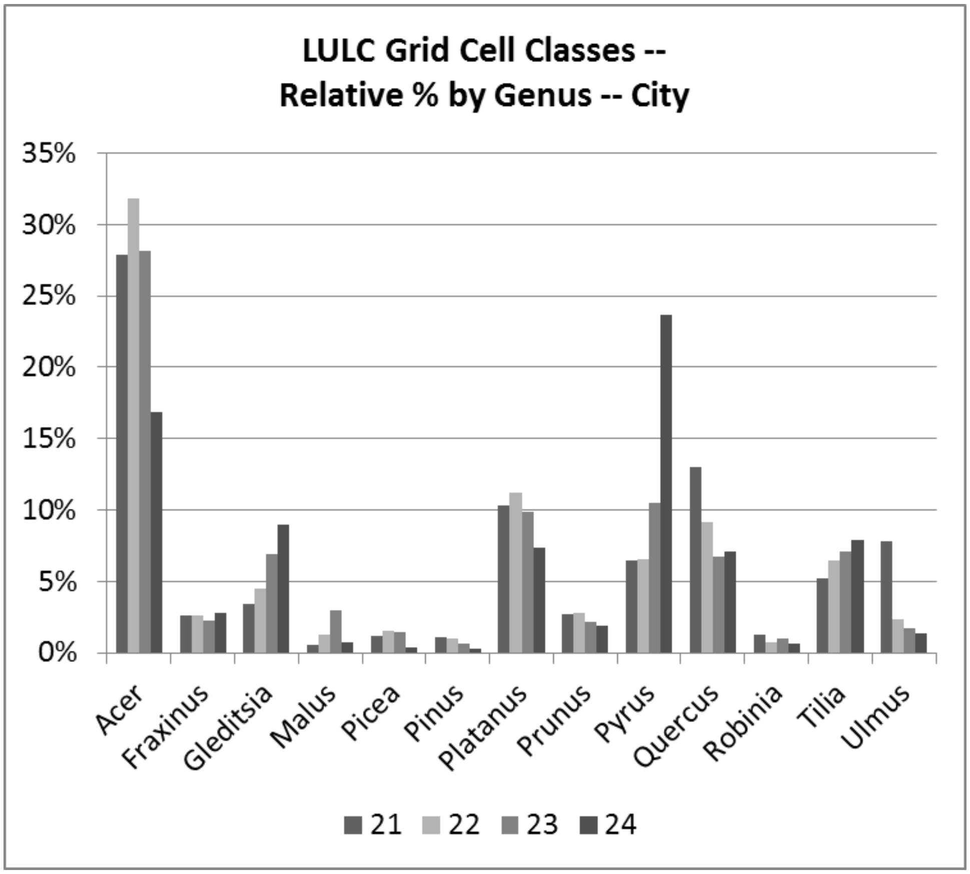


Figure 4.9 Relative percentages of LULC grid cell classes characterized by development (21, 22, 23, and 24) by prevalent New York State street tree genera in New York State cities

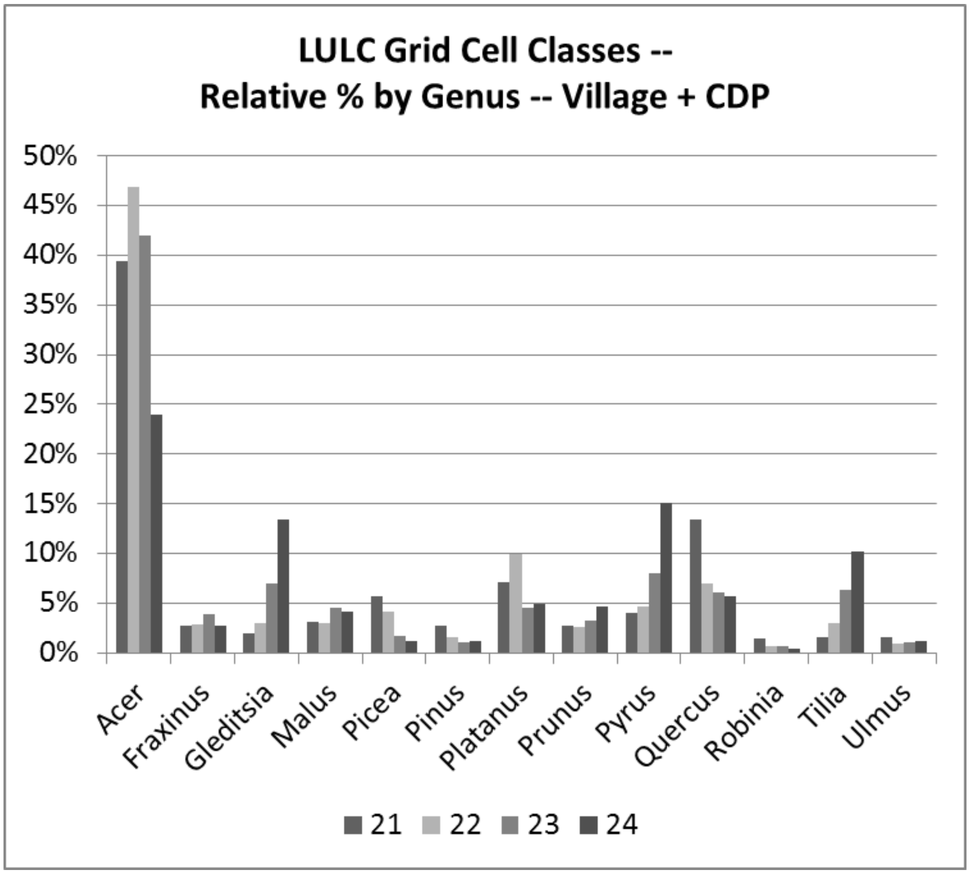


Figure 4.10 Relative percentages of LULC grid cell classes characterized by development (21, 22, 23, and 24) by prevalent New York State street tree species in New York State villages and CDPs

It must be noted, however, that many street tree inventories in New York State are not geo-referenced. In fact, the number of geo-referenced street tree inventories obtained in New York State is meaningfully fewer than the number of street tree inventories obtained in New York State overall. Also, many geo-referenced street tree inventories (42.5% of all geo-referenced street tree inventories) are located in 1990 USDA Plant Hardiness Zone 7 municipalities.

This substantial representation of Zone 7 data can potentially bias results since street tree species and genera vary by 1990 USDA Plant Hardiness Zone class. For example, *Pyrus* is more prevalent in Zone 7 than in Zone 5 while the reverse is true for *Malus*. It is possible that a larger effect would be seen for *Malus* due to development intensity (i.e. *Malus* percentages would increase more significantly from LULC grid cell class 21 to LULC grid cell class 24) if additional geo-referenced data was obtained from municipalities in Zone 5. It must be noted additionally that the number of grid cells in LULC grid cell class 24 is far fewer than the number of grid cells in LULC grid cell classes 21, 22, and 23. Results for LULC grid cell class 24, consequently, contain more variability than results for the other grid cell classes. Finally, the number of geo-referenced street tree inventories obtained from New York State cities is meaningfully fewer than the number of geo-referenced street tree inventories obtained from New York State villages and CDPs. This is somewhat to be expected since the number of New York State villages and CDPs far exceeds the number of New York State cities. Nevertheless, the relatively small number of cities from which geo-referenced street tree inventory data has been obtained cautions the reliability and validity of results when percentages of street tree species and genera are differentiated on the basis of municipality type.

Despite the caveats and data limitations, land use, and more specifically NLCD LULC grid cell classes 21, 22, 23, and 24 reflecting differences in development intensity, look to have explanatory power regarding New York State street tree populations. Small and medium sized trees such as *Pyrus calleryana*, *Malus species*, and *Tilia cordata* appear more prevalent as development intensity increases and large sized trees such as *Acer saccharum* and *Platanus x acerifolia* appear less prevalent as development intensity increases. Municipality type (i.e. city, village, and CDP) may also impact street tree species and genera prevalence although effects for municipality type and development intensity can be expected to be somewhat multi-collinear. Since development intensity generally increases from north to south in New York State and 1990 USDA Plant Hardiness Zones mirror to a great extent a north-south geographic axis, multi-collinearity is also likely to be an issue between land use effects associated with development intensity and effects associated with 1990 USDA Plant Hardiness Zone classes. Attention must be given, therefore, not to overfit any model seeking to explain street tree populations in New York State which includes land use variables such as municipality type, LULC grid cell classes, and 1990 USDA Plant Hardiness Zone classes. In addition, possible bias in sample data towards increased intensity of development must be considered.

Sociodemographics

Similar to land use, studies correlating urban trees with sociodemographics have focused more on urban forest canopy cover than on street tree canopy cover or street tree characteristics. For example, Iverson and Cook (2000) found for Chicago, IL that increased tree canopy cover was associated with higher median household income; Heynen and Lindsey (2003) found for sixty urban areas in Central Indiana that increased urban tree canopy cover was associated with higher levels of educational attainment and older housing stock, but not with population density or median household income; Hope et al (2003) found for Phoenix, AZ that increased plant diversity was associated with higher median family income and older housing; and Heynen et al (2006) found for Milwaukee, WI that census tracts with higher median household income, more non-Hispanic White residents, and lower housing vacancy rates were more likely to have greater tree canopy cover. Fewer studies have correlated street tree canopy cover with sociodemographics. Grove et al (2006) found for Baltimore, MD that tree canopy cover in public rights-of-way was associated with housing age and lifestyle behavior while Landry and Chakraborty (2009) found for Tampa, FL a significantly lower proportion of street tree canopy cover in neighborhoods with higher proportions of African-American residents, lower median household incomes, and lower proportions of owner-occupied housing. Two studies correlated street tree counts rather than street tree canopy cover with sociodemographics. Lovasi et al (2008) found for New York, NY that street tree density (i.e. density of street trees per km^2) was higher in the most densely populated areas and in areas with less poverty, and Neckerman et al (2009) also found for New York, NY that poorer census tracts with at least 20% of residents living in poverty had fewer street trees.

Just as correlations with urban forest tree canopy cover should not be assumed to translate directly into land use correlations with either street tree canopy cover or street tree population characteristics, correlations with urban forest canopy cover do not necessarily apply to sociodemographic correlations with street tree canopy cover or street tree population characteristics. Nevertheless, the preponderance of findings from the studies above coupled with the two studies focusing on street tree counts in New York City suggest that there may be a sociodemographic effect on street tree populations and, more specifically, an effect for median household income and higher levels of educational attainment. Therefore, the following methodology was employed to assess sociodemographic correlations with street tree populations in New York State. Sociodemographic data was obtained from the United States Census Bureau (Census 2000 Summary File 1 [SF 1] - 100 Percent Data and Census 2000 Summary File 3 [SF 3] - Sample Data) for all Census Places in New York State (e.g. cities, villages, and CDPs). Data from the 2000 Census was used because data from the 2010 Census for a comprehensive range of variables at the geographic scale of the Census Place was not sufficiently available at time of writing.

Data for the following Census variables was analyzed: housing unit density (i.e. housing units per square mile), median age, median household income, median year structure built, percent population below the poverty line, percent population with a college degree, percent owner occupied housing, percent rural population, and population density. Comparisons were made between data for New York State Census Places where street tree inventory data has been obtained and data for all New York State Census Places to assess possible biases contained in the street tree inventory data sample. Paired *t*-tests and Mann–Whitney *U* tests for Census variables revealed the following: no statistically significant differences were found statewide for median age and percent population with a college degree between New York State Census Places where street tree inventory data has been obtained and all New York State Census Places. Statistically significant differences were found statewide for housing unit density, median household income, median year structure built, percent population below the poverty line, percent owner occupied housing, percent rural population, and population density such that Census Places where street tree inventory data has been obtained are characterized by less housing unit density, lower median household income, older median structures built, a higher percentage of population below the poverty line, a lower percentage of owner occupied housing, a lower percentage of rural population, and higher population density than all New York State Census Places.

While these statewide differences in Census variables between New York State Census Places where street tree inventory data has been obtained and all New York State Census Places are noteworthy, they do not necessarily mean that the street tree inventory data sample is irreparably biased. Further examination suggests that these statewide differences reflect disproportionate representation between Census Places downstate and Census Places upstate contained in the sample compared to all Census Places statewide. More specifically, Census Places upstate are more heavily represented in the sample than they are statewide. For example, the number of Census Places where street tree inventory data has been obtained represents 7% of all Census Places located downstate in 1990 USDA Plant Hardiness Zone 7 compared to 15% elsewhere in New York State. Because significant differences exist between upstate and downstate Census variables and the number of upstate Census Places where street tree inventory data has been obtained has been overrepresented relative to the number of all Census Places upstate, these differences have been reflected in differences found between New York State Census Places where street tree inventory data has been obtained and all New York State Census Places. If additional street tree inventory datasets were obtained from Census Places located in 1990 USDA Plant Hardiness Zone 7, differences found between New York State Census

Places where street tree inventory data has been obtained and all New York State Census Places would likely be mitigated. In the absence of that event, the upstate overrepresentation in sample Census variables will be accounted for by grouping Census variables by 1990 USDA Plant Hardiness Zone classes and analyzing them on that basis, consistent with what has been done in assessing other potential model variables.

The efficacy of this strategy was tested for median household income. Whereas statistically significant differences were found for median household between New York State Census Places where street tree inventory data has been obtained and all New York State Census Places, and statistically significant differences can also be found for median household income between all New York State Census Places in all 1990 USDA Plant Hardiness Zone classes (i.e. mean household income for all Census Places is 33830 for Zones 3 + 4, 38366 for Zone 5, 58562 for Zone 6, and 81856 for Zone 7), there are no statistically significant differences for median household income between Census Places where street tree inventory data has been obtained and all Census Places in Zone 3 + 4, Zone 6, or Zone7; there is a slight statistically significant difference in Zone 5 (e.g. 38366 for all Census Places vs. 34896 for Census Places where street tree inventory data has been obtained) which can be attributed to efforts by Cooperative Extension in some Zone 5 counties to conduct street tree inventories in smaller, less affluent, rural communities. Therefore, correlations between sociodemographic variables and street tree populations in New York State will be assessed by 1990 USDA Plant Hardiness Zone class to mitigate statewide differences in Census variables between New York State Census Places where street tree inventory data has been obtained and all New York State Census Places.

Linear regressions were run in which street trees per mile by 1990 USDA Plant Hardiness Zone class were regressed with sociodemographic variables. Street trees per mile rather than prevalent street tree species and genera was selected as the dependent variable since there is no evidence in the peer reviewed scientific literature to suggest that street tree species and genus composition within a municipality is influenced by sociodemographic factors. However, as cited above, there is evidence in this literature to indicate that sociodemographic factors do influence street tree numbers and canopy cover within a municipality although only one study (Heynen & Lindsey 2003) analyzed relationships between canopy cover and sociodemographic variables across multiple municipalities. Regression results found statistically significant effects (α =.10) for at least two zone classes for median household income, median year structure built, and percent population with a college degree; statistically significant effects (α =.10) for at least two zone classes were not found for housing unit density, median age, percent population below the poverty line, percent owner occupied housing, percent rural population, and population density. For these variables, percent population with a college degree explained more variability in street trees per mile than median year structure built and median household income, and median year structure built explained more variability than median household income. Models were then run for each 1990 USDA Plant Hardiness Zone class with street trees per mile as a dependent variable and median household income, median year structure built, and percent population with a college degree as independent variables. The model for 1990 USDA Plant Hardiness Zones 3 + 4 was not found to be statistically significant for any of these variables; median age and percent rural population were found to be statistically significant individually, but not when combined in a model. The model for 1990 USDA Plant Hardiness Zone 5 was found to be statistically significant with median household income, median year structure built, and percent population with a college degree included as independent variables, but none of these variables was found to be significant when combined with the others in the model. Percent population with a college degree was found to have the most explanatory power of these variables for street trees per mile in 1990 USDA Plant Hardiness Zone 5; an increase in street trees per mile was correlated with an increase in percent population with a college degree. The model for 1990 USDA Plant Hardiness Zone 6 was found to be statistically significant with median household income, median year structures built, and percent population with a college degree included as independent variables, but only median household income was found to be significant when combined with the others in the model. Median household income was found to have the most explanatory power of these variables for street trees per mile in 1990 USDA Plant Hardiness Zone 6; an increase in street trees per mile was correlated with an increase in median household income. The model for 1990 USDA Plant Hardiness Zone 7 was found to be statistically significant with median household income, median year structure built, and percent population with a college degree included as independent variables, but only one variable at a time was found to be significant when combined with the others in the model. Median household income was found to have the most explanatory power of these variables for street trees per mile in 1990 USDA Plant Hardiness Zone 7; an increase in street trees per mile was correlated with an increase in median household income.

Results overall suggest that median household income has more explanatory power than either median year structure built or percent population with a college degree in explaining variability in street trees per mile. On a statewide basis, results from a linear regression with street trees per mile as the dependent variable and median household income as the independent variable found a statistically significant effect (r^2 = 39.0, prob > F <.0001, n = 110). However, when 1990 USDA Plant Hardiness Zone class was added to the regression model, median household income was no longer statistically significant (α =.10) and 1990 USDA Plant Hardiness Zone class was the superior predictor. Therefore, median household income as well as median year structure built and percent population with a college degree would not appear to be warranted for inclusion in a model predicting street trees per mile on a statewide basis, especially in comparison to 1990 USDA Plant Hardiness Zone class. Although the explanatory power for these sociodemographic variables appears limited across multiple municipalities, it is possible they might have greater explanatory power within a municipality, but that analysis is beyond the scope of this research.

Additional Factors

Clark et al (1997) hypothesized a model of urban forest sustainability with three principal components: species and age diversity in urban trees, community support for urban forestry, and comprehensive management of urban trees as a municipal resource. Included in those components were employment and training of staff dedicated to tree care, planting, and pruning; municipal ordinances protecting existing trees and replacing trees lost to development; and citizen groups such as shade tree boards or commissions advocating for funding and policies promoting urban forestry. Thus, staff, ordinances, and advocacy were hypothesized as factors associated with the health and sustainability of urban and community trees.

The Community Accomplishment Reporting System (CARS) of the United States Forest Service's Urban and Community Forestry Program requires each state to collect data from municipalities regarding the number of communities that (1) employ or retain professional forestry staff to manage urban and community trees, (2) have adopted ordinances or polices focused on planting, protecting, and maintaining urban and community trees, and (3) have local advisory or advocacy organizations such as tree boards or commissions that advocate for the planting, protection, and maintenance of urban and community trees (USDA Forest Service 2011). Data is collected for cities, villages, and CDPs, but not for towns. Rines et al (2011) studied CARS data for Massachusetts municipalities and found positive correlations (Spearman's *p*) between professional staff, ordinances, and advocacy groups with population size, median household income, and percentage of residents with a college degree. These findings are consistent with findings made by Zhang et al (2007) in a statewide telephone survey of Alabama residents that individuals holding a full-time job and with an annual income greater than $75,000 were more likely to donate money and volunteer time in support of urban forestry programs and activities; findings made by Dickerson et al (2001) that communities in Illinois with higher mean annual per capita income and higher levels of educational attainment were more likely than poorer, less educated communities to employ professional personnel to make tree care decisions; and findings made by Lorenzo et al (2000) that residents of a New Orleans, LA suburb with annual incomes greater than $40,000 and a college education were more likely to appreciate the value of urban trees and financially support urban forestry programs than residents with annual incomes less than $25,000 and a high school education. Although these studies identify potential sociodemographic bias in components hypothesized to promote urban forest sustainability, they do not directly correlate these components to tree population characteristics such as species and genus composition, relative age distribution, or species diversity that are closely associated with the long term health of urban and community trees.

To assess whether Urban and Community Forestry CARS statistics and the presence or absence of professional staff, ordinances, and advocacy groups could be helpful in explaining variability in New York State street tree populations, CARS statistics for the years 2007 through 2010 were obtained from the United States Forest Service for communities in New York State. Duplicate responses were removed to create a list of communities credited with professional staff, ordinances, or advocacy groups for any one of the years between 2007 and 2010. Spearman's *p* correlations were run for all New York State Census Places in which the presence or absence of professional staff, ordinances, or advocacy groups was correlated with population size, median household income, and percentage of population with a college degree. Population size was found to be significantly correlated (α =.10) with professional staff (r = 0.28), ordinances (r = 0.31), and advocacy groups (r = 0.25); median household income was found to be significantly correlated with advocacy groups (r = –0.11), but significant correlations were not found for professional staff or ordinances; and percentage of population with a college degree was found to be significantly correlated for professional staff (r = 0.14), ordinances (r = 0.18), and advocacy groups (r = 0.08). These results are similar to results found by Rines et al (2011) for population size, but differ somewhat from Rines et al for percentage of population with a college degree and differ greatly from Rines et al for median household income. Reasons for these differences are not clear.

Spearman's p correlations were then run where the presence or absence of professional staff, ordinances, or advocacy groups were correlated with species diversity and street trees per mile for those New York State municipalities where street tree inventory data has been obtained. Three species diversity indices were used for these correlations: the Inverse of Simpson's Diversity Index (SDI), the Shannon-Weiner Diversity Index, and Fisher's alpha. Fisher's alpha was included because Kempton and Taylor (1976) have argued that it better represents species abundance (i.e. is less sensitive to and does not over-represent rarer species) than other species diversity indices and, therefore, depending on the structure of the population being sampled, may be a superior measure. Professional staff was found to be significantly correlated (α =.10) with Shannon-Weiner (r = 0.19) and Fisher's alpha (r = 0.36), but a significant correlation was not found for the Inverse SDI. Ordinances and advocacy groups were found to be significantly correlated with Fisher's alpha (r = 0.18 and r = 0.19 respectively), but significant correlations were not found for the Inverse SDI or Shannon-Weiner.

Spearman's *p* correlations were also run for the presence or absence of professional staff, ordinances, and advocacy groups with street trees per mile for New York State municipalities where street tree inventory data has been obtained and values for street trees per mile can be calculated. Professional staff, ordinances, or advocacy groups were found to be significantly correlated with street trees per mile ($r = 0.24$, $r = 0.41$, and $r = 0.28$ respectively).

Lastly, Spearman's *p* correlations were run for the presence or absence of professional staff, ordinances, and advocacy groups with annual benefits per tree for New York State municipalities where street tree inventory data has been obtained and values for annual benefits per tree can be calculated. Professional staff, ordinances, or advocacy groups were found to be significantly correlated with annual benefits per tree ($r = –0.33$, $r = –0.28$, and $r = –0.27$ respectively).

The results above suggest that CARS statistics, and specifically the presence or absence of professional staff, ordinances, and advocacy groups, might be helpful in explaining variability in New York State street tree populations. Professional staff appears to have greater explanatory power with respect to species diversity than ordinances or advocacy groups, but professional staff, ordinances, and advocacy groups all appear to have explanatory power for street trees per mile and annual benefits per tree. The negative correlations for annual benefits per tree are not immediately explainable. One possible explanation could be that communities with professional staff, ordinances, and advocacy groups are associated with increased numbers of younger, newly planted street trees relative to communities without professional staff, ordinances, and advocacy groups; since younger, newly planted street trees provide fewer annual benefits than older, more mature street trees, communities with increased numbers of recent street tree plantings could be expected to provide fewer annual benefits per tree than communities where recent street tree plantings have not been as abundant.

Species and Genus Composition

Four zone classes (i.e. Zones 3 + 4, Zone 5, Zone 6, and Zone 7) based on 1990 USDA Plant Hardiness Zones have been hypothesized as a significant predictor variable in estimating species and genus composition in New York State. This hypothesis has been predicated on the assumption that plant hardiness zones reflect differences in minimum winter temperature and that minimum winter temperature affecting plant hardiness is an important factor in explaining the distribution and prevalence of street tree species and street tree genera. Annual precipitation, elevation, and distance from the equator have also been hypothesized as predictor variables in estimating species and genus composition in New York State. Linear regressions found statistically significant effects (α =.10) for many, but not all prevalent street tree species and genera for annual precipitation, elevation, and distance from the equator.

Distance from the equator explained more variability than annual precipitation and elevation, and annual precipitation explained more variability than elevation. However, when included in ANCOVA (Analysis of Co-variance) models with 1990 USDA Plant Hardiness Zone classes, zone class was found to be a better predictor of street tree species and genera than annual precipitation, elevation, and distance from the equator and variance inflation factor (VIF) values, a measure of multi-collinearity between variables in a model, were consistently and significantly larger for distance from the equator and elevation with zone class than values for annual precipitation with zone class. Therefore, annual precipitation would appear to be a better candidate than distance from the equator or elevation for inclusion with 1990 USDA Plant Hardiness Zone class in a model estimating species and genus composition in New York State. Development intensity and municipality type have been hypothesized as additional predictor variables in estimating species and genus composition in New York State. Relative percentages of NLCD LULC grid cell classes 21, 22, 23, and 24 for New York State municipalities have been identified as measures of development intensity and cities have been differentiated from villages and Census Designated Places (CDPs) for capturing effects based on municipality type.

Linear regressions were run for prevalent New York State street tree species and genera with species and genera percentages of municipality street tree populations as dependent variables and 1990 USDA Plant Hardiness Zone class, annual precipitation, municipality type, and relative percentages of NLCD LULC grid cell classes 21, 22, 23, and 24 as independent variables. Findings (α =.10) are as follows:

- 1990 USDA Plant Hardiness Zone class is the best predictor variable for most prevalent street tree genera and many prevalent street tree species

- Municipality type generally explains less variability than 1990 USDA Plant Hardiness Zone class, but is the best predictor variable for several street tree species and genera, including *Tilia* and *Gleditsia*, for which statistically significant effects were not found for 1990 USDA Plant Hardiness Zone class and whose percentages increase with development intensity (i.e. greater for city than village or CDP)

- Statistically significant effects were found for annual precipitation and LULC grid cell classes 21, 22, 23, and 24, but these effects were not consistent and often found to be multi-collinear with effects for 1990 USDA Plant Hardiness Zone class and municipality type

- In a multivariate model containing both 1990 USDA Plant Hardiness Zone and municipality type, the two variables were frequently found to be multi-collinear and 1990 USDA Plant Hardiness Zone class explained much more variability than did municipality type

Based on these findings, 1990 USDA Plant Hardiness Zone class will be used to calculate mean species and genus percentages and 90% confidence interval levels by zone class based on summary statistics from assembled street tree inventory data. Annual precipitation, municipality type, and LULC grid cell classes 21, 22, 23, and 24 will not be used to calculate mean species and genus percentages and 90% confidence interval levels. Because municipality type was found to be the best predictor variable of mean percentages for some species and genera including *Tilia* and *Gleditsia* where summary statistics indicate greater prevalence in cities than in villages and CDPs, additional analysis may be warranted to explore adjustments to mean species and genus percentages and 90% confidence levels to account for effects due to municipality type. However, a conservative approach is advisable in this regard pending the collection of additional data since r^2 values for municipality type are comparatively slight (i.e. r^2 for *Gleditsia* = 0.13 and r^2 for *Tilia* = 0.08), municipality type effects seem concentrated in 1990 USDA Plant Hardiness Zone 7, and municipality type effects may already be captured substantially at the zone class level.

CHAPTER 5

STATEWIDE ESTIMATES

A statistical model for making reliable and valid statewide estimates of New York State street trees has been delineated predicated on stratifying data and weighting summary statistics by 1990 USDA Plant Hardiness Zone class. Objectives of the model include calculation of street tree numbers statewide for prevalent species and genera and calculation of annual benefits statewide provided by street trees. These calculations are based on the following measures:

(i) Summed street length of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places

(ii) Means for street trees per meter and street trees per mile of streets expected to contain street trees

(iii) Mean percentages of prevalent street tree species and genera

(iv) Mean annual benefits per street tree

Calculation of street tree numbers statewide for prevalent species and genera is based on the following construct:

$$\boxed{\begin{array}{c}\text{Total Number of}\\ \text{Street Trees}\end{array}} \quad \text{X} \quad \boxed{\begin{array}{c}\text{Mean Percentage of}\\ \text{Species or Genus}\end{array}} \quad = \quad \boxed{\begin{array}{c}\text{Total Number of}\\ \text{Species or Genus}\end{array}}$$

Calculation of annual benefits statewide provided by street trees is based on the following construct:

$$\boxed{\begin{array}{c}\text{Total Number of}\\ \text{Street Trees}\end{array}} \quad \text{X} \quad \boxed{\begin{array}{c}\text{Mean Benefits (\$)}\\ \text{Per Street Tree}\end{array}} \quad = \quad \boxed{\begin{array}{c}\text{Total Benefits (\$)}\\ \text{For All Street Trees}\end{array}}$$

Common to these constructs is a calculation of the total number of street trees statewide which is based in turn on the following construct:

$$\boxed{\begin{array}{c}\text{Street Length}\\ \text{Expected to}\\ \text{Contain Street}\\ \text{Trees}\end{array}} \quad \text{X} \quad \boxed{\begin{array}{c}\text{Number of Street}\\ \text{Trees per Unit}\\ \text{Street Length}\end{array}} \quad = \quad \boxed{\begin{array}{c}\text{Total Number of}\\ \text{Street Trees}\end{array}}$$

Street Tree Numbers Statewide

Estimates of street tree numbers statewide are based on two measures: first, summed street length of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places and, second, means for the number of street trees per meter of streets expected to contain street trees or, alternatively, the number of street trees per mile of streets expected to contain street trees.

Summed street length of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places was calculated according to a methodology explained in Chapter 2. Results, contained in Table 2.6, indicate that summed street length in meters of streets expected to contain street trees is 83,392,547 meters.

Means and standard errors for street trees per meter and street trees per mile of streets expected to contain street trees by 1990 USDA Plant Hardiness Zone Class were calculated (Table 3.14). Means were weighted by percentages of summed street length of streets expected to contain street trees by 1990 USDA Plant Hardiness Zone Class (Table 3.1) according to the formula:

$$((w1 * m1) + (w2 * m2) + (w3 * m3) + (w4 * m4)) / (w1 + w2 + w3 + w4)$$

Where $m1$, $m2$, $m3$, and $m4$ denote the group means for street trees per meter or street trees per mile of street expected to contain street trees (i.e. the means for each 1990 USDA Plant Hardiness Zone class) and $w1$, $w2$, $w3$, and $w4$ denote the different weights for each group (i.e. percentages of summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places for each 1990 USDA Plant Hardiness Zone class). The weighted statewide mean of street trees per meter of street was estimated to be 0.0500003 trees per meter and the weighted statewide mean of street trees per mile of street was estimated to be 80.47 trees per mile.

To calculate an upper and lower 90% confidence level for the weighted statewide means, a standard error for the weighted statewide means was calculated according to the formula:

$$\sqrt{}\ ((se1^2 * w1^2) + (se2^2 * w2^2) + (se3^2 * w3^2) + (se4^2 + w4^2))/ (w1 + w2 + w3 + w4)$$

Where $se1$, $se2$, $se3$, and $se4$ denote the group standard error for street trees per meter or street trees per mile of street expected to contain street trees (i.e. the standard error for each 1990 USDA Plant Hardiness Zone class). The standard error of the statewide weighted mean of street trees per meter of street was found to be 0.002440023 and the standard error of the statewide weighted mean of street trees per mile of street was found to be 3.926838067. The upper 90% confidence level of the weighted mean was calculated as

0.0500003 + (1.645 * 0.002440023) or 0.05401716 and the lower 90% confidence level of the weighted mean was calculated as 0.0500003 – (1.645 * 0.002440023) or 0.045989484.

Based on these measures, street tree numbers statewide can be estimated in meters as follows:

Tree Numbers = 83,392,547 meters * 0.0500003 trees per meter = 4,169,904

90% UCL = 83,392,547 meters * 0.05401716 trees per meter = 4,504,629

90% UCL= 83,392,547 meters * 0.045989484 trees per meter = 3,835,180

Street Tree Numbers Statewide for Prevalent Species and Genera

Estimates of street tree numbers statewide for prevalent species and genera are based on two measures: first, street tree numbers statewide as calculated above and, second, mean percentages of street tree populations for prevalent species and genera. Conceptually, if the estimated number of street trees statewide is 4,169,904 and the statewide weighted mean percentage of street tree species *x* is *y* %, then the estimated number of street trees statewide for species *x* can be calculated as 4,169,904 * *y* %.

Statewide weighted mean percentages were calculated for prevalent species and genera according to the formula:

$$((w1 * m1) + (w2 * m2) + (w3 * m3) + (w4 * m4)) / (w1 + w2 + w3 + w4)$$

Where $m1$, $m2$, $m3$, and $m4$ denote the group means for each species and genus (i.e. the mean percentages for each1990 USDA Plant Hardiness Zone class for each species and genus) and $w1$, $w2$, $w3$, and $w4$ denote the different weights for each group (i.e. percentages of summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places for 1990 USDA Plant Hardiness Zone classes in New York State) as stated in Table 3.1.

Standard errors for the statewide weighted mean percentages have been calculated according to the formula:

$$\surd\ ((se1^2 * w1^2) + (se2^2 * w2^2) + (se3^2 * w3^2) + (se4^2 + w4^2))/ (w1 + w2 + w3 + w4)$$

Where $se1$, $se2$, $se3$, and $se4$ denote the group standard errors for each species and genus (i.e. the standard error of mean percentages for each 1990 USDA Plant Hardiness Zone class for each species and genus). Results from these calculations for prevalent street tree species are contained in Table 5.1

and results from these calculations for prevalent street tree genera are contained in Table 5.2. For example, the mean statewide percentage of *Acer platanoides* (Norway Maple) is calculated to be 20.65% and there is a 90% probability that the statewide percentage of *Acer platanoides* is between 22.44% and 18.87% of the statewide street tree population. Similarly, the mean statewide percentage of the *Acer* (Maple) genus is calculated to be 44.14% and there is a 90% probability that the statewide percentage of *Acer* is between 47.97% and 40.30% of the statewide street tree population.

Table 5.1 Statewide mean percentages, standard errors, and upper and lower 90% confidence levels for prevalent New York State street tree species

Species	**Mean**	**Std Err**	**90% UCL**	**90% LCL**
Acer platanoides	20.65	1.08	22.44	18.87
Acer saccharum	9.89	0.67	11.00	8.79
Acer saccharinum	5.79	0.70	6.94	4.65
Platanus x acerifolia	5.72	0.78	7.01	4.43
Acer rubrum	5.29	0.43	5.99	4.59
Gleditsia triacanthos	5.21	0.50	6.04	4.38
Pyrus calleryana	4.72	0.69	5.85	3.59
Quercus palustris	2.77	0.27	3.22	2.32
Tilia cordata	2.69	0.29	3.17	2.22
Malus species	2.45	0.22	2.81	2.09
Fraxinus pennsylvanica	1.98	0.18	2.28	1.68
Quercus rubra	1.69	0.14	1.91	1.46
Picea abies	1.27	0.15	1.51	1.03
Pinus strobus	1.08	0.17	1.37	0.80
Robinia pseudoacacia	1.03	0.15	1.29	0.78

Table 5.2 Statewide mean percentages, standard errors, and upper and lower 90% confidence levels for prevalent New York State street tree genera

Genus	Mean	Std Err	90% UCL	90% LCL
Acer	44.14	2.33	47.97	40.30
Quercus	7.03	0.51	7.86	6.19
Platanus	5.79	0.75	7.02	4.56
Pyrus	5.36	0.81	6.69	4.04
Gleditsia	4.96	0.46	5.73	4.20
Tilia	4.09	0.39	4.72	3.45
Fraxinus	3.35	0.24	3.76	2.95
Picea	2.99	0.27	3.43	2.55
Prunus	2.84	0.21	3.19	2.49
Malus	2.47	0.23	2.85	2.09
Pinus	1.63	0.18	1.92	1.33
Ulmus	1.36	0.20	1.70	1.03
Robinia	1.06	0.16	1.32	0.80

Based on these measures, street tree numbers statewide can be estimated as follows:

Number of Trees = 4,169,904 trees * (Species or Genus) Mean%

Trees 90% UCL = 4,504,629 trees * (Species or Genus) 90% UCL

Trees 90% LCL = 3,835,180 trees * (Species or Genus) 90% LCL

For example, the estimated number of *Fraxinus* (Ash) street trees statewide could be estimated as follows:

Fraxinus Trees = 4,169,904 trees * 3.3545% = 139,881

Fraxinus 90% UCL= 4,504,629 trees * 3.7566% = 169,222

Fraxinus 90% LCL = 3,835,180 trees * 2.9524% = 113,231

Based on this methodology, estimates have been made for the mean number of trees and upper and lower 90% confidence levels for prevalent street tree species and genera. Estimates for prevalent street tree species are contained in Table 5.3 and estimates for prevalent street tree genera are contained in Table 5.4.

Table 5.3 Estimates of numbers of trees for prevalent street tree species

Species	**Mean**	**90% UCL**	**90% LCL**
Acer platanoides	861226	1010677	723711
Acer saccharum	412474	495291	337044
Acer saccharinum	241595	312596	178263
Platanus x acerifolia	238622	315909	169975
Acer rubrum	220749	269983	176198
Gleditsia triacanthos	217254	271943	168101
Pyrus calleryana	196721	263385	137619
Quercus palustris	115638	145217	89077
Tilia cordata	112332	142802	85050
Malus species	102025	126453	80011
Fraxinus pennsylvanica	82678	102916	64462
Quercus rubra	70414	86204	56131
Picea abies	52960	67973	39547
Pinus strobus	45214	61657	30676
Robinia pseudoacacia	43065	57939	29887

Table 5.4 Estimates of numbers of trees for prevalent street tree genera

Genus	Mean	90% UCL	90% LCL
Acer	1840400	2160762	1545694
Quercus	292986	354112	237449
Platanus	241533	316214	175069
Pyrus	223673	301377	154849
Gleditsia	206900	257897	161013
Tilia	170381	212840	132199
Fraxinus	139881	169222	113231
Picea	124747	154715	97745
Prunus	118446	143582	95633
Malus	103172	128594	80298
Pinus	67864	86487	51198
Ulmus	56819	76562	39332
Robinia	44136	59517	30515

Statewide Annual Benefits Provided by Street Trees

Estimates of statewide annual benefits provided by street trees are based on two measures: first, street tree numbers statewide as calculated above and, second, statewide means for benefits per street tree. Conceptually, if the estimated number of street trees statewide is 4,169,904 and mean statewide benefits per street tree is *z*, then estimated statewide annual benefits provided by street trees can be calculated as 4,169,904 * *z*.

Mean benefits per street tree have been found to be 133.75 (dollars) with a median of 135.57, a standard deviation of 24.05, a standard error of 2.17, and upper and lower 90% confidence levels of 137.32 and 130.18. An analysis of benefits per street tree by 1990 USDA Plant Hardiness Zone classes (e.g. Zones 3 + 4, Zone 5, Zone 6, and Zone 7) found no statistically significant difference between the means of benefits per street tree for each 1990 USDA Plant Hardiness Zone class. Therefore, the unweighted statewide mean and standard error will be used to estimate statewide annual benefits provided by street trees and upper and lower 90% confidence levels. Estimates are as follows:

Statewide Annual Benefits = 4,169,904 trees * $133.75/tree = $557,724,660

Benefits 90% UCL = 4,504,629 trees * $137.32/tree = $ 618,575,654

Benefits 90% LCL= 3,835,180 trees * $130.18/tree = $ 499,263,732

Discussion

In the example above estimating the number of *Fraxinus* (Ash) street trees statewide, the range between the upper and lower 90% confidence levels was found to be 55,991 trees or a 20.98% difference relative to the mean. Similarly for statewide annual benefits, the range between the upper and lower 90% confidence levels was found to be $119,311,922 or a 9.84% difference relative to the mean. For numbers of street trees statewide, the range between the upper and lower 90% confidence levels was found to be 669,499 trees or an 8.03% difference relative to the mean. These are not small numbers and ideally they would be reduced to improve estimate precision. At the same time, accuracy and reliability must not be compromised and a conservative approach to accuracy and reliability has been followed throughout the estimation process. For example, a preliminary iteration for calculating street trees per length of street involved estimates by linear regression in which street tree numbers per municipality were regressed on street length per municipality to yield the following model:

Number of Trees = - 694.2735 + 0.0591657 * Street Length Meters

Although this model appeared highly accurate and statistically significant (r^2 = .987, $p < .0001$, RMSE = 3412.98), further analysis revealed extreme heteroskedasticity (i.e. unequal variance) for the error terms. Therefore, while the range between the upper and lower 90% confidence levels predicted by the regression model was only 83,319 trees or a 1.81% difference relative to the mean, these estimates could not be accepted as reliable and the model could not be used.

Estimate precision can typically be improved (i.e. standard error can be reduced) by increasing sample size. In other words, if additional street tree inventory datasets evenly distributed by 1990 USDA Plant Hardiness Zone class were included in these analyses, it is likely although not certain that precision would be improved for measures of street trees per meter and street trees per mile of streets expected to contain street trees, percentages of prevalent street tree species and genera, and annual benefits per street tree. Precision could also be improved with greater standardization of street tree inventory data. As has been mentioned previously, considerable variation exists between municipalities in data collection (e.g. types of data fields and data field measures) which in turn limits the ability to group datasets and creates uncertainty about the accuracy of data collection. Finally, it should be recognized that plant biogeography which includes the geographic distribution of street trees is intrinsically variable and, depending on the geographies and the tree species and genera in question, may not yield standard errors that can easily be reduced.

CHAPTER 6

TESTING ESTIMATES

Street tree numbers statewide for prevalent species and genera and annual benefits statewide provided by street trees have been calculated on the basis of a sample of 142 street tree inventory datasets widely distributed throughout New York State. These estimates have been made in the belief that sample data statistics accurately predict statistics for the statewide population of street trees and by inference for the many municipalities in New York State, including cities, villages, and CDPs, that do not have a street tree inventory. Assessing the accuracy of statewide estimates is inherently problematic since statistics for the statewide population are unknown. It might be tempting to assess the accuracy of statewide estimates by conducting street tree inventories in municipalities lacking inventories and comparing these results to the statewide estimates. To do so, however, would be to commit “ecologic fallacy” since Robinson (1950) has demonstrated that correlations made at the ecologic, or group, level are not implicitly valid at the individual level. In other words, estimates made for New York State will not necessarily predict statistics accurately for its individual municipalities. However, as Subramanian et al (2009) have pointed out in a critique of Robinson, correlations can operate at multiple levels and correlations not valid at one level might be valid at another. A multilevel approach seems appropriate in the context of this research since statewide estimates for New York State have been predicated on stratifying and weighting sample data by 1990 USDA Plant Hardiness Zone class. Accordingly, while conducting test inventories in municipalities lacking inventories and comparing these results to the statewide estimates would be of questionable validity, comparing results from individual municipalities to summary statistics at the zone class level might have more legitimacy especially with regard to statistically significant differences and trends found at the zone class level.

To evaluate whether results from test inventories would reflect differences and trends found at the zone class level, street tree inventories were conducted in municipalities lacking an inventory from each of the four 1990 USDA Plant Hardiness Zone classes in New York State: Unadilla (Zones 3 + 4), Greene (Zone 5), Lima and Shortsville (Zone 6), and Great Neck Plaza (Zone 7). Another reason for selecting these municipalities was their relatively small area enabling one person to inventory all street trees in each municipality by walking survey in two days. Finally, these municipalities are all villages. Because municipality type has been found to have a slight effect on street tree populations, restricting test inventories to villages avoids biasing results by municipality type. Demographic statistics for each municipality are contained in Table 6.1 and their locations are shown in Figure 6.1. In each municipality, all street trees located in the right-of-way were inventoried. Data taken for each tree included genus and species, trunk diameter at breast height (DBH), planting location type (front yard or lawn, treelawn, sidewalk tree pit, and median), wood and leaf condition, presence or absence of single or triple phase utility wires, street addresses, and GPS coordinates. Park trees were excluded from the surveys although municipalities typically manage these trees. Data was given to the respective municipality for use in managing its street tree population.

Table 6.1 Demographics for test inventory municipalities

Municipality	Unadilla	Greene	Lima	Shortsville	Great Neck Plaza
Zone Class	3+4	5	6	6	7
County	Otsego	Chenango	Livingston	Ontario	Nassau
Population (2010 Census)	1,128	1,580	2,139	1,439	6,707
Area (Sq Miles)	1.037	1.068	1.346	0.700	0.312
Population Density (Sq Mile)	1,088	1,480	1,589	2,156	21,485
Housing Units	559	804	847	603	4,052
Housing Unit Density (Sq Mile)	539	753	629	861	12,980

Figure 6.1 Locations of test inventory municipalities

Genus Composition

449 streets trees were inventoried in Unadilla, 410 in Greene, 577 in Lima, 368 in Shortsville, and 715 in Great Neck Plaza. The genus composition of inventoried trees was analyzed and compared to statistics for the most prevalent genera in each village's 1990 USDA Plant Hardiness Zone class. Table 6.2 compares summary statistics for the most prevalent street tree genera in New York State to inventory percentages for prevalent street tree genera in Unadilla, Greene, Lima, Shortsville, and Great Neck Plaza.

Table 6.2 Comparison of summary statistics for the most prevalent street tree genera in New York State to inventory percentages for prevalent street tree genera in Unadilla, Greene, Lima, Shortsville, and Great Neck Plaza

Zones 3 + 4 (*n* = 31)	**Mean**	**UCL 90%**	**LCL 90%**	**Unadilla**
Acer	54.774	59.337	50.211	65.033
Fraxinus	5.396	6.605	4.188	2.895
Malus	4.490	5.788	3.193	3.118
Gleditsia	4.304	5.538	3.069	5.568
Picea	4.162	5.132	3.191	6.013
Quercus	3.960	5.170	2.751	3.563
Tilia	3.551	4.630	2.473	1.336
Pyrus	2.245	3.046	1.444	0.891
Pinus	2.041	3.004	1.077	2.227
Ulmus	1.353	1.934	0.771	2.004
Prunus	1.342	1.760	0.923	3.786
Robinia	1.271	2.031	0.511	0.668
Platanus	0.101	0.189	0.012	0.000

Zone 5 (*n* = 60)	**Mean**	**UCL 90%**	**LCL 90%**	**Greene**
Acer	55.880	67.747	44.013	71.220
Picea	5.706	6.918	4.495	3.902
Gleditsia	4.915	5.959	3.871	1.707
Malus	4.277	5.185	3.369	7.073
Fraxinus	3.693	4.477	2.909	4.878
Tilia	3.234	3.920	2.547	0.000
Quercus	2.895	3.510	2.281	1.463
Pyrus	2.423	2.937	1.908	7.561
Prunus	2.198	2.664	1.731	0.488
Pinus	1.713	2.077	1.349	0.244
Ulmus	0.904	1.096	0.712	0.244
Robinia	0.822	0.997	0.648	0.000
Platanus	0.654	0.792	0.515	0.000

Zone 6 (*n* = 28)	Mean	UCL 90%	LCL 90%	Lima	Shortsville
Acer	51.080	56.659	45.502	49.220	78.261
Gleditsia	6.164	7.436	4.893	9.359	0.815
Quercus	4.852	6.551	3.153	0.173	0.000
Tilia	4.472	5.879	3.065	2.946	1.087
Platanus	3.812	5.746	1.878	0.520	0.000
Fraxinus	3.713	4.689	2.738	15.078	1.359
Pyrus	3.302	4.667	1.936	0.347	0.543
Prunus	2.509	3.249	1.769	3.466	9.511
Malus	2.304	3.104	1.504	3.640	3.533
Picea	2.032	2.713	1.352	2.080	0.272
Ulmus	1.616	2.366	0.867	0.000	0.000
Pinus	1.351	1.835	0.867	0.867	0.000
Robinia	1.123	1.710	0.536	1.386	0.272

Zone 7 (*n* = 23)	Mean	UCL 90%	LCL 90%	Great Neck Plaza
Acer	25.830	29.590	22.071	10.629
Platanus	13.142	16.323	9.961	8.112
Quercus	13.042	14.895	11.190	19.580
Pyrus	10.359	14.046	6.671	26.434
Tilia	4.559	5.826	3.293	8.112
Gleditsia	4.108	5.840	2.377	4.755
Prunus	4.048	4.730	3.366	1.818
Fraxinus	2.215	2.621	1.810	0.699
Pinus	1.694	2.332	1.055	0.420
Ulmus	1.501	2.205	0.797	0.140
Picea	1.389	1.988	0.790	0.000
Robinia	1.130	1.646	0.614	0.000
Malus	0.659	1.001	0.318	0.000

Some test inventory results are similar to the zone class means and fall within the zone class upper and lower 90% confidence levels while others do not. For example, the percentage of *Acer* found in Lima (49.220%) is similar to the mean (51.080%) and falls within the upper and lower 90% confidence levels (56.659% and 45.502%) for Zone 6 class level statistics. Likewise, the percentage of *Gleditsia* found in Great Neck Plaza (4.755%) is similar to the mean (4.108%) and falls within the upper and lower 90% confidence levels (5.840% and 2.377%) for Zone 7 class level statistics. However, the percentage of *Acer* found in Greene (71.220%), the percentage of *Fraxinus* found in Lima (15.078%), and the percentage of *Pyrus* found in Great Neck Plaza (26.434%) are larger than the mean percentages for those genera in their respective zone classes and do not fall within the zone class upper and lower 90% confidence levels. Likewise, the percentage of *Fraxinus* found in Unadilla (2.895%) and the percentage of *Tilia* found in Shortsville (1.087%) are smaller than the mean percentages for those genera in their respective zone classes and do not fall within the zone class upper and lower 90% confidence levels.

Similarities and differences between test inventory genera percentages and zone class summary statistics are to some extent less significant than they seem. For example, the percentage of *Acer* found in Greene (71.220%) is large and differs meaningfully from the zone class mean, but it should not be seen as atypical since 11 of 60 inventoried municipalities in Zone 5 (11.67%) have even larger percentages of *Acer*. Likewise, the percentage of *Fraxinus* found in Lima (15.078%) is large and exceeds the percentages of *Fraxinus* for all other municipalities in Zone 6 for which data has been obtained, but several municipalities in Zones 3 + 4 and Zone 5 have percentages of *Fraxinus* that are larger. Moreover, given that comparisons are being made between zone class statistics and statistics from one or two test inventories in each zone class, it is not surprising that substantial differences exist between them. It is likely that conducting additional test inventories per zone class would smooth out deviations between zone class and test inventory statistics although, in the case of Zone 6, two inventories were not sufficient to have done so as can be seen from the averaging of Lima and Shortsville percentages in Table 6.3. For example, averaging percentages from these two inventories has produced a test statistic for *Gleditsia* that falls within the zone class upper and lower 90% confidence levels whereas the individual test statistics for Lima and Shortsville do not. However, averaging percentages from these two inventories has produced a test statistic for *Acer* that does not fall within the zone class upper and lower 90% confidence levels whereas the individual test statistic for Lima approximates the zone class mean.

Table 6.3 Comparison of summary statistics for the most prevalent street tree genera in Zone 6 to the average of inventory percentages for prevalent street tree genera in Shortsville and Lima

Zone 6 (*n* = 28)	**Mean**	**Median**	**UCL 90%**	**LCL 90%**	**L + S**
Acer	51.080	46.995	56.659	45.502	63.740
Gleditsia	6.164	5.523	7.436	4.893	5.087
Quercus	4.852	3.134	6.551	3.153	0.087
Tilia	4.472	2.640	5.879	3.065	2.017
Platanus	3.812	1.653	5.746	1.878	0.260
Fraxinus	3.713	2.119	4.689	2.738	8.218
Pyrus	3.302	2.022	4.667	1.936	0.445
Prunus	2.509	1.844	3.249	1.769	6.489
Malus	2.304	1.282	3.104	1.504	3.586
Picea	2.032	1.177	2.713	1.352	1.176
Ulmus	1.616	0.673	2.366	0.867	0.000
Pinus	1.351	0.738	1.835	0.867	0.433
Robinia	1.123	0.473	1.710	0.536	0.829

Finally, as suggested previously, the real value of the test inventory statistics may be in corroborating differences and trends for genera percentages found at the zone class level. In other words, test inventory statistics can provide perspective on the validity of 1990 USDA Plant Hardiness Zone class as a predictor variable of statewide street tree population characteristics and the reliability of statewide estimates made on that basis. Although only five test inventories have been conducted with regard to this study and more test inventories would be desirable, test inventory statistics appear consistent with zone class level differences and trends. For example, percentages of *Acer*, *Picea*, and *Malus* decline between Zone 7 and the other zone classes and percentages of *Quercus*, *Platanus*, and *Pyrus* increase. More specifically, *Acer* prevalence in Great Neck Plaza is reduced from *Acer* prevalence in Unadilla, Greene, Lima, and Shortsville, similar to what has been found at the zone class level (Figure 6.2). Likewise, *Quercus* prevalence is greater in Great Neck Plaza than in Unadilla, Greene, Lima, and Shortsville similar to what has been found at the zone class level (Figure 6.3). Therefore, while test inventory statistics for prevalent street tree genera do not conflate in many cases with zone class level statistics and perhaps should not be expected to, they do appear to reflect and confirm zone class level differences and trends.

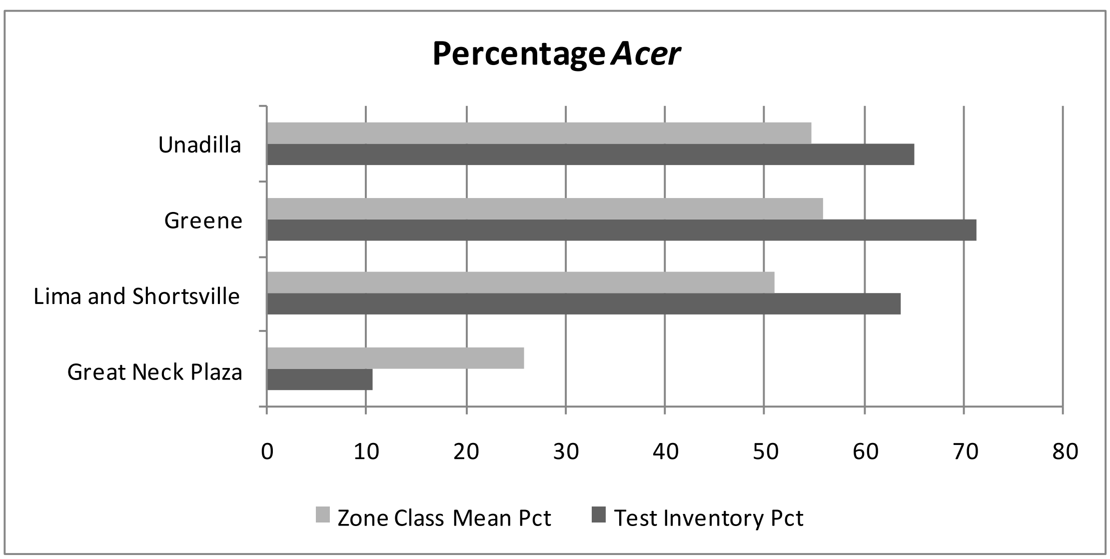


Figure 6.2 *Acer* prevalence for zone class and test inventories

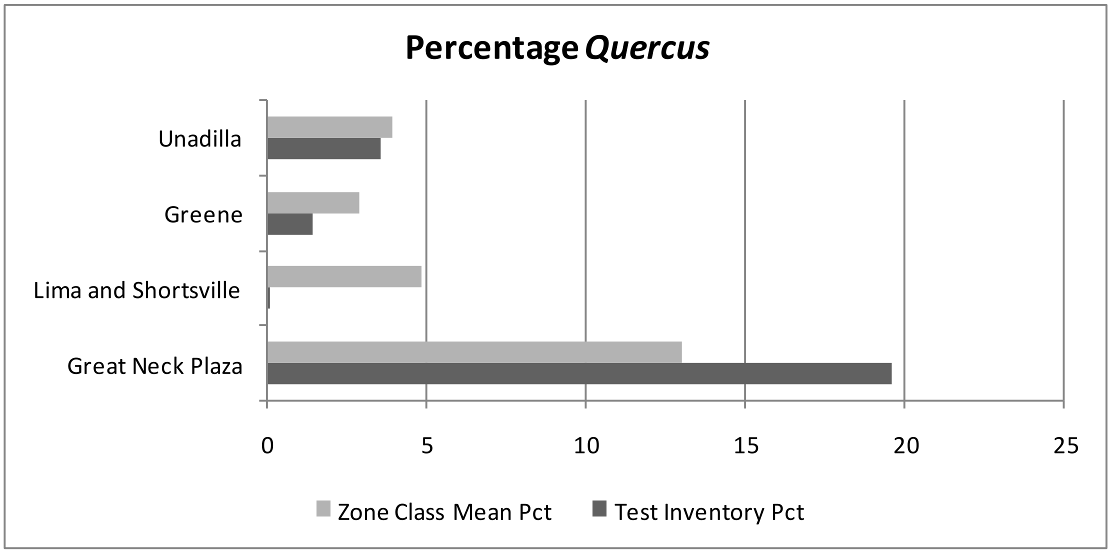


Figure 6.3 *Quercus* prevalence for zone class and test inventories

Species Composition

An analysis similar to the one performed for genus composition was performed for species composition with test inventory results from Unadilla, Greene, Lima, Shortsville, and Great Neck Plaza. The species composition of inventoried trees was analyzed and compared to statistics for the most prevalent species in each village's respective 1990 USDA Plant Hardiness Zone class. Table 6.3 compares summary statistics for the most prevalent street tree species in New York State to inventory percentages for prevalent street tree species in Unadilla, Greene, Lima, Shortsville, and Great Neck Plaza.

Table 6.4 Comparison of summary statistics for the most prevalent street tree species in New York State to inventory percentages for prevalent street tree species in Unadilla, Greene, Lima, Shortsville, and Great Neck Plaza

Zones 3 + 4 (*n* = 28)	**Mean**	**Median**	**UCL 90%**	**LCL 90%**	**Unadilla**
Acer saccharum	20.612	20.135	24.118	17.106	46.102
Acer platanoides	15.524	14.330	19.445	11.603	13.808
Acer saccharinum	6.844	3.708	10.000	3.688	2.673
Acer rubrum	6.243	5.727	7.377	5.109	0.668
Malus species	4.540	3.339	5.944	3.136	3.118
Gleditsia triacanthos	4.222	3.120	5.396	3.049	5.568
Tilia cordata	2.295	0.839	3.206	1.384	1.336
Pyrus calleryana	2.281	1.919	3.114	1.448	0.891
Fraxinus pennsylvanica	2.252	1.418	3.036	1.468	1.559
Quercus rubra	1.867	0.639	2.700	1.033	2.895
Pinus strobus	1.565	0.368	2.363	0.766	2.227
Robinia pseudoacacia	1.110	0.289	1.820	0.400	0.668
Picea abies	0.867	0.390	1.201	0.533	3.786
Quercus palustris	0.661	0.343	1.003	0.319	0.223
Platanus x acerifolia	0.057	0.000	0.113	0.002	0.000

Zone 5 (*n* = 58)	**Mean**	**Median**	**UCL 90%**	**LCL 90%**	**Greene**
Acer platanoides	21.248	20.234	23.485	19.010	29.756
Acer saccharum	20.190	17.702	23.296	17.085	24.146
Acer saccharinum	6.232	4.000	7.741	4.723	0.732
Acer rubrum	5.288	4.383	6.032	4.545	12.683
Gleditsia triacanthos	4.853	3.720	5.722	3.984	1.707
Malus species	4.245	3.415	5.010	3.481	6.829
Picea abies	2.728	2.000	3.300	2.156	2.683
Pyrus calleryana	2.440	1.910	2.986	1.894	7.561
Tilia cordata	2.277	1.189	2.875	1.680	0.000
Fraxinus pennsylvanica	2.145	1.439	2.680	1.609	4.390
Quercus rubra	1.472	1.095	1.762	1.181	0.732
Pinus strobus	0.862	0.219	1.219	0.504	0.244
Robinia pseudoacacia	0.833	0.355	1.066	0.600	0.000
Quercus palustris	0.760	0.261	1.066	0.455	0.488
Platanus x acerifolia	0.485	0.178	0.651	0.318	0.000

Zone 6 (*n* = 28)	Mean	Median	UCL 90%	LCL 90%	L + S
Acer platanoides	28.359	28.110	32.060	24.657	26.170
Acer saccharinum	8.877	4.252	12.238	5.517	3.813
Gleditsia triacanthos	6.205	5.686	7.405	5.004	9.359
Acer saccharum	5.626	3.518	7.421	3.831	15.425
Acer rubrum	5.498	3.963	7.316	3.680	2.946
Platanus x acerifolia	3.283	0.833	5.147	1.419	0.347
Tilia cordata	3.238	2.065	4.442	2.035	2.426
Pyrus calleryana	3.184	1.830	4.481	1.888	0.347
Quercus palustris	2.397	0.441	3.519	1.274	0.000
Malus species	2.220	1.235	2.982	1.458	3.640
Fraxinus pennsylvanica	1.761	0.833	2.430	1.092	14.385
Quercus rubra	1.229	0.714	1.616	0.841	0.173
Robinia pseudoacacia	1.082	0.417	1.643	0.522	1.386
Pinus strobus	0.785	0.093	1.187	0.383	0.173
Picea abies	0.673	0.311	1.045	0.301	1.040

Zone 7 (*n* = 18)	Mean	Median	UCL 90%	LCL 90%	GNP
Acer platanoides	14.729	12.493	18.274	11.185	6.993
Platanus x acerifolia	13.551	12.921	16.972	10.130	8.112
Pyrus calleryana	8.534	6.890	11.619	5.450	26.434
Quercus palustris	5.265	5.773	6.103	4.427	18.462
Gleditsia triacanthos	4.875	3.121	6.933	2.818	4.755
Acer rubrum	4.859	4.903	5.956	3.763	1.119
Acer saccharum	2.665	1.557	3.736	1.594	0.559
Tilia cordata	2.646	1.970	3.384	1.908	6.014
Acer saccharinum	2.424	2.380	3.008	1.840	0.559
Quercus rubra	2.220	1.961	2.687	1.753	0.979
Fraxinus pennsylvanica	1.979	1.859	2.444	1.515	0.280
Pinus strobus	1.395	0.307	2.066	0.725	0.420
Robinia pseudoacacia	1.125	0.724	1.614	0.636	0.000
Picea abies	0.762	0.104	1.181	0.343	0.000
Malus species	0.664	0.352	1.067	0.261	0.000

Mirroring results for genus composition, some test inventory results are similar to the zone class means and fall within the upper and lower 90% confidence levels. Others do not. For example, the percentage of *Gleditsia triacanthos* found in Great Neck Plaza (4.755%) is similar to the mean (4.875%) and falls within the upper and lower 90% confidence levels (6.933% and 2.818%) for Zone 7 class level statistics. Likewise, the percentage of *Acer platanoides* found in Lima (26.170%) is similar to the mean (28.359%) and falls within the upper and lower 90% confidence levels (32.060% and 24.657%) for Zone 6 class level statistics. However, the percentage of *Acer rubrum* found in Greene (12.683%), the percentage of *Fraxinus pennsylvanica* found in Lima (14.385%), and the percentage of *Quercus palustris* found in Great Neck Plaza (18.462%) are larger than the mean percentages for those genera in their respective zone classes and do not fall within the upper and lower 90% confidence levels. Likewise, the percentage of *Acer platanoides* found in Great Neck Plaza (6.993%) and the percentage of *Gleditsia triacanthos* found in Greene (1.707%) are smaller than the mean percentages for those genera in their respective zone classes and do not fall within the upper and lower 90% confidence levels.

As with genus composition, the real value of the test inventory statistics may be in corroborating differences and trends for species percentages found at the zone class level. Results from the five test inventories indicate general agreement between differences at the zone class level for prevalent street tree species and differences at the zone class level for the test inventory municipalities. For example, percentages of *Acer saccharum* and *Acer saccharinum* decline between Zone 7 and the other zone classes while the percentages of *Platanus x acerifolia*, *Pyrus calleryana*, and *Quercus palustris* increase. More specifically, *Acer platanoides* prevalence in Great Neck Plaza is reduced from *Acer platanoides* prevalence in Unadilla, Greene, Lima, and Shortsville, similar to what has been found at the zone class level (Figure 6.4). Likewise, *Platanus x acerifolia* prevalence is greater in Great Neck Plaza than in Unadilla, Greene, Lima, and Shortsville similar to what has been found at the zone class level (Figure 6.5). Therefore, while test inventory statistics for prevalent street tree species do not conflate in many cases with zone class level statistics, they do appear to reflect and confirm zone class level differences and trends.

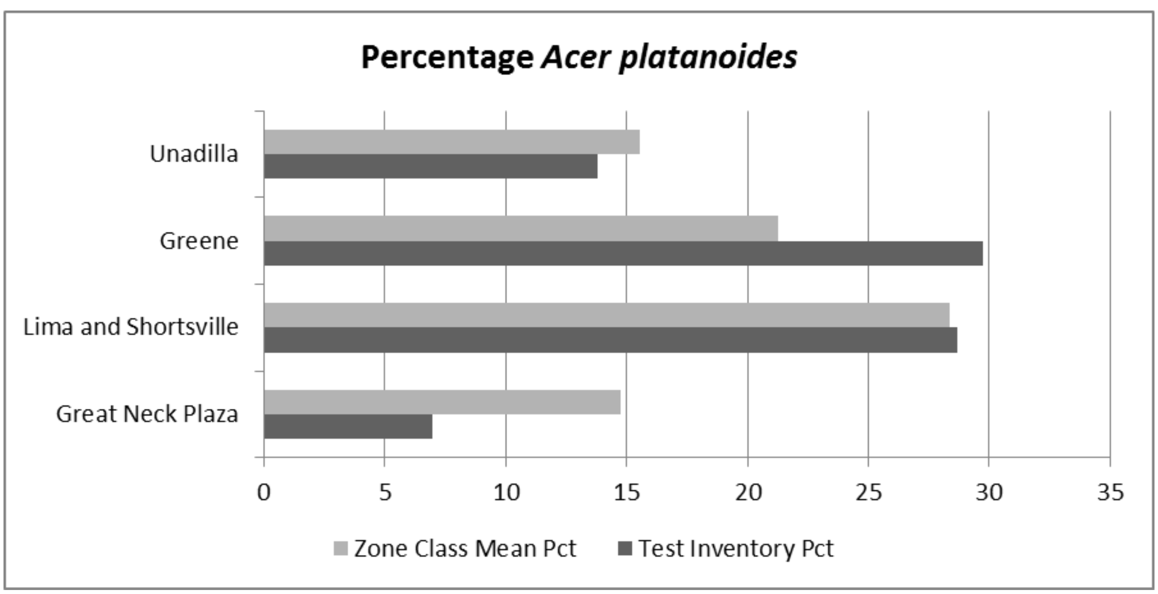


Figure 6.4 *Acer platanoides* prevalence for zone class and test inventories

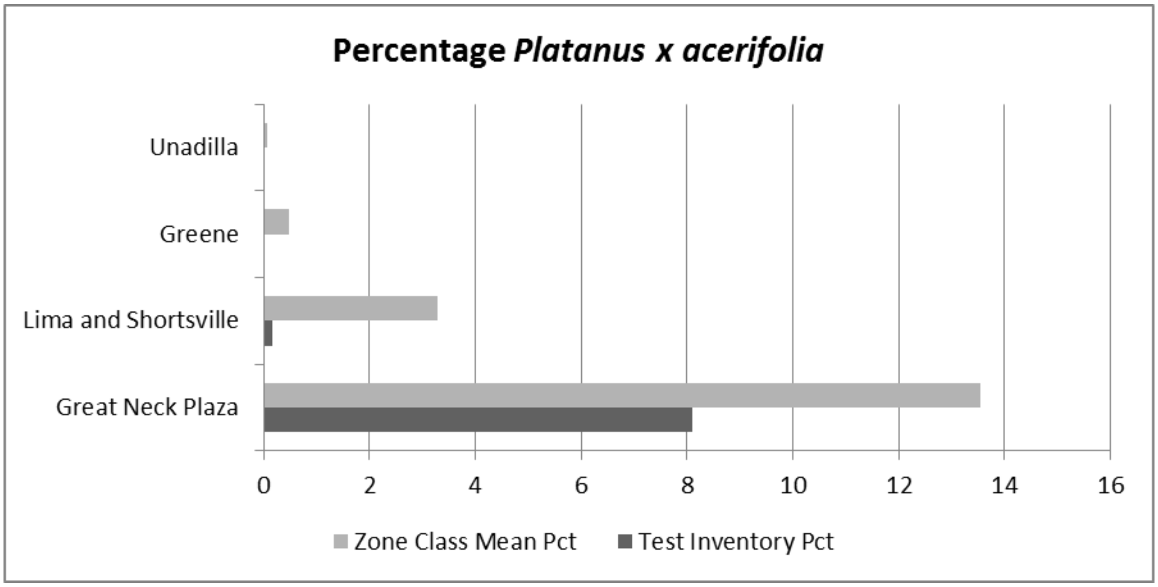


Figure 6.5 *Platanus x acerifolia* prevalence for zone class and test inventories

Species and Genus Diversity

As a general rule, no tree species should comprise more than 10% and no tree genera should comprise more than 20% of a municipality's street tree population (Santamour 1990). Statistics from all five test inventory municipalities violate this rule. For example, with respect to genera, 71.22% of street trees in Greene and 78.261% of street trees in Shortsville are *Acer* and 26.43% of street trees in Great Neck Plaza are *Pyrus*. With respect to species, 46.10% of street trees in Unadilla are *Acer saccharum* and 20.653% of street trees in Lima are *Acer platanoides*.

Two measures, the inverse of Simpson's Diversity Index (SDI) and the Shannon-Weiner Diversity Index, have been used to assess species diversity in New York State street tree populations. Inverse SDI and Shannon-Weiner values were calculated for test inventory municipalities. Results are contained in Table 6.5 with results for Lima and Shortsville (Zone 6) averaged.

Table 6.5 Species diversity measures for 1990 USDA Plant Hardiness Zone classes and test inventory municipalities

	Test Inventory Inverse SDI	Zone Class Inverse SDI	Test Inventory Shannon-Weiner	Zone Class Shannon-Weiner
Zones 3 + 4	4.13	8.08	2.21	2.55
Zone 5	5.62	8.16	2.13	2.64
Zone 6	5.73	8.20	2.24	2.60
Zone 7	7.32	11.79	2.41	2.95

Similar to species and genus composition, test inventory statistics for the Inverse SDI and Shannon-Weiner do not conflate with zone class means. For example, Inverse SDI and Shannon-Weiner values for test inventories are less than the Inverse SDI and Shannon-Weiner mean values for their respective zone class. Possible explanations include the small areas of the villages, the small number of trees to be inventoried as compared to larger municipalities, and the absence of professional staff making street tree management decisions. However, test inventory statistics do reflect differences and trends found at the zone class level in which species diversity increases with milder temperatures. For example, test inventory Inverse SDI values increase from Zones 3 + 4 to Zone 7 as they do for the zone class Inverse SDI mean (Figure 6.6). Likewise, notwithstanding the test inventory Shannon-Weiner value for Zone 5, test inventory Shannon-Weiner values increase from Zones 3 + 4 to Zone 7 as they do for the zone class Shannon-Weiner mean (Figure 6.7). Therefore, while test inventory statistics for species diversity do not conflate with zone class level means, they do appear to reflect and confirm differences and trends found at the zone class level.

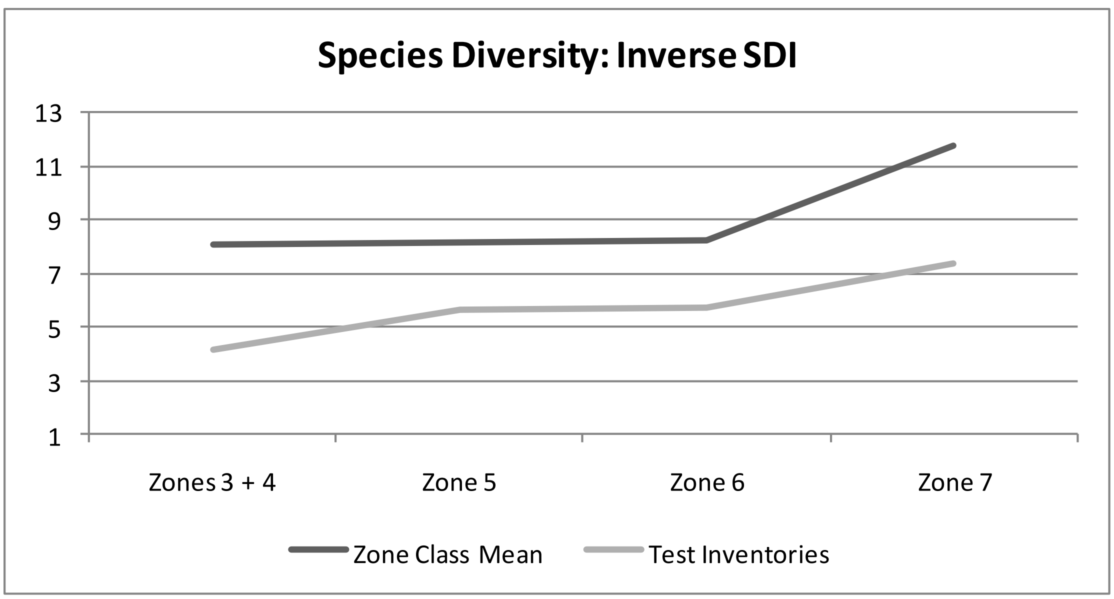


Figure 6.6 Inverse SDI values for zone class and test inventories

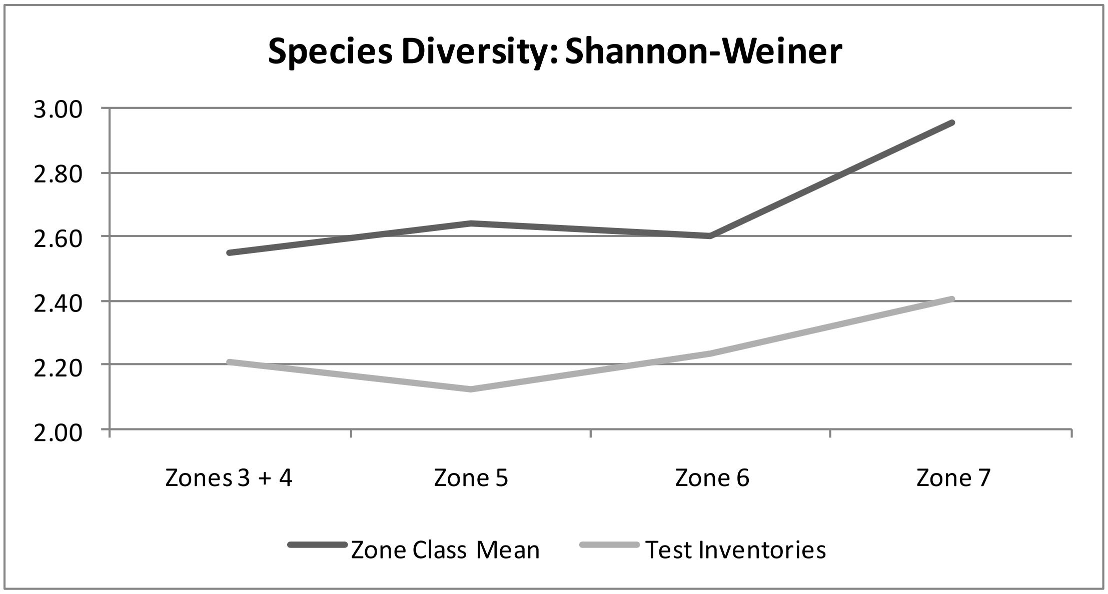


Figure 6.7 Shannon-Weiner values for zone class and test inventories

Relative Age Distribution

The relative age distribution of each test inventory's street trees was analyzed. Ideally, there needs to be a sufficient number of younger, smaller trees to account for the loss of trees over time to create a j-shaped profile in the age distribution by DBH class. Table 6.6 contains the relative percentages per tree diameter class for each test inventory and Figure 6.8 illustrates their tree diameter profiles. While none of the test inventory municipalities has the ideal j-shaped age distribution profile, between the municipalities Shortsville has the largest relative percentage in the 0-5.9 DBH inch class and Great Neck Plaza the smallest. Unadilla is notable in that its 30-35.9 DBH inch class has the largest values compared to its other classes, indicating a street tree population characterized by an unusually high proportion of large, old trees.

Table 6.6 Relative percentages per tree diameter class for test inventories

DBH in Inches	0 to 5.9	6 to 11.9	12 to 17.9	18 to 23.9	24 to 29.9	30 to 35.9	36 to 41.9	42 +
Unadilla	10.24	14.92	14.03	12.03	16.04	19.38	9.13	4.23
Greene	20.98	21.22	25.61	12.20	10.00	6.83	2.68	0.49
Lima	13.17	34.84	28.25	9.88	7.45	3.47	2.08	0.87
Shortsville	23.16	24.52	17.98	14.17	8.99	6.54	2.45	2.18
Great Neck Plaza	8.95	33.43	34.41	11.19	7.69	3.36	0.56	0.42

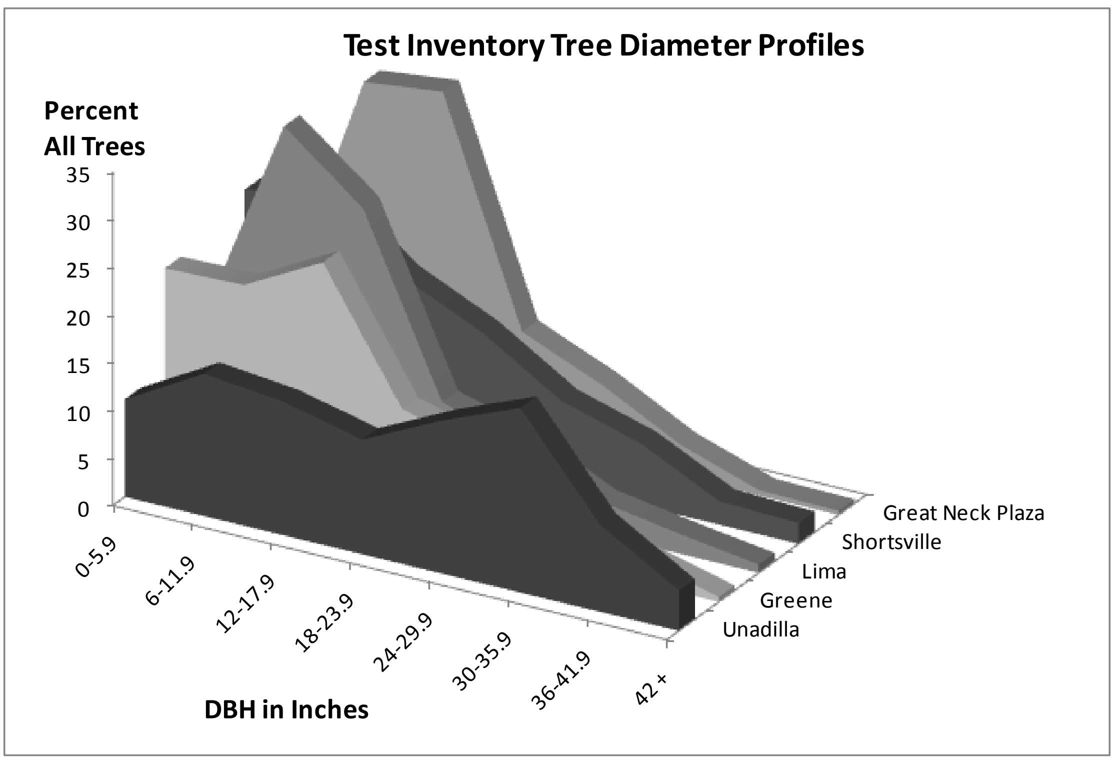


Figure 6.8 Tree diameter profiles for test inventories

The relative age distribution of test inventory street trees was compared to the relative age distribution of street trees statewide. Analysis of street trees statewide found an insufficient number of younger trees and a disproportionate share of older trees (Figure 3.4). DBH inch class percentages for the test inventories were averaged and compared to statewide DBH inch class percentages (Figure 6.9). Results indicate similarity between the test inventory and statewide profiles with a disproportionate share of older trees and too few younger trees being planted to maintain street tree populations at current levels.

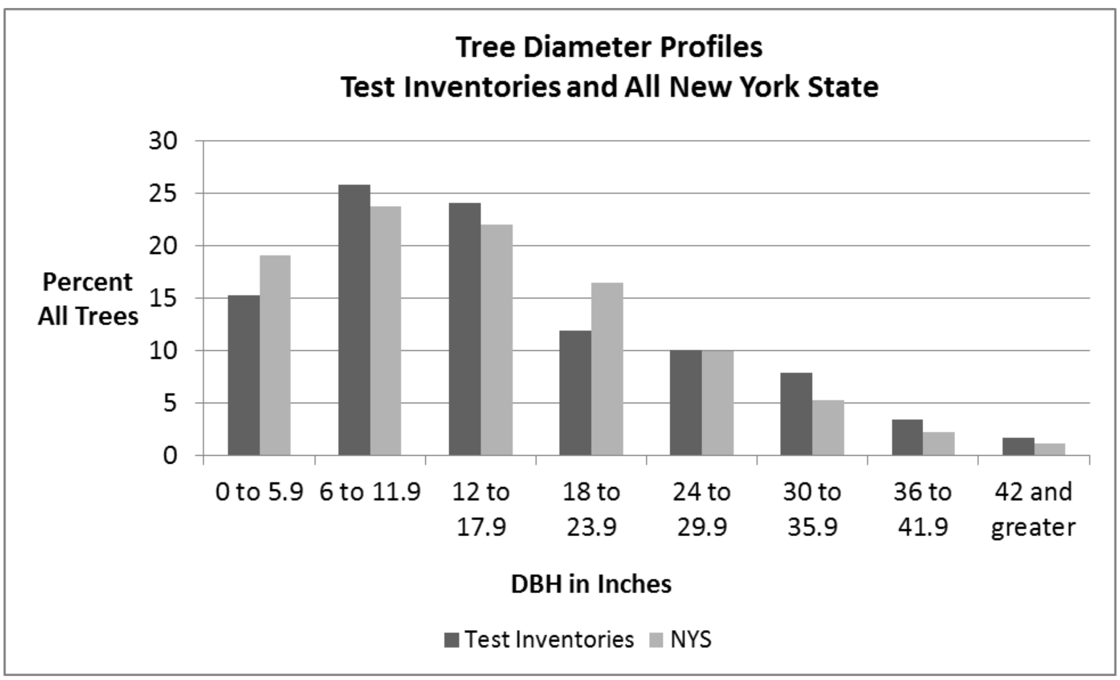


Figure 6.9 Comparison of test inventory and statewide tree diameter profiles

Street Tree Benefits

For test inventory municipalities, i-Tree Streets was used to calculate total annual benefits (energy conservation, air quality improvement, CO2 reduction, stormwater control, and property value increase) provided by street trees. Total annual benefits (in dollars) per municipality were divided by the number of street trees surveyed in that municipality to calculate benefits per street tree per municipality in dollars. Results are contained in Table 6.7.

Table 6.7 Street tree benefits per tree ($) for test inventories

	Unadilla	Greene	Lima	Shortsville	Great Neck Plaza
Street Trees Inventoried	449	410	577	368	715
Total Annual Benefits ($)	82,132	55,896	76,557	43,542	106,637
Benefits per Tree ($)	183.33	136.33	132.68	118.97	149.14

Statewide estimates of benefits per street tree found no statistically significant difference by 1990 USDA Plant Hardiness Zone class. Mean benefits per street tree statewide were calculated to be $133.75 with upper and lower 90% confidence levels of $137.32 and $130.18. Mean benefits per street tree for test inventories are calculated to be $144.09, a value which does not fall within the statewide upper and lower 90% confidence levels. This deviation between the statewide and test inventory means can be attributed to Unadilla which, as documented in Figure 6.8, has an unusually high proportion of large, old trees and possesses the largest benefits per street tree measure found by this study in New York State. If Unadilla is considered an outlier and excluded from the test inventory mean, the mean of the test inventories is $134.28 which falls within the statewide upper and lower 90% confidence levels and approximates the statewide mean.

Benefits per mile of street length were also calculated for test inventories with values for Lima and Shortsville averaged. Results are contained in Table 6.8 and compared to zone class means and upper and lower 90% confidence levels. Test inventory values fall within the upper and lower 90% confidence levels for Zones 5, 6, and 7, but do not fall within the upper and lower 90% confidence levels for Zones 3 + 4. This deviation between the zone class mean and the Zones 3 + 4 test inventory statistic can again be attributed to Unadilla's high proportion of large, old trees.

Table 6.8 Street tree benefits per street mile ($) for test inventory zone class

	Zone Class Mean	90% UCL	90% LCL	Test Inventories
Zones 3 + 4	7382.86	5672.00	9093.72	9715.41
Zone 5	6702.38	5590.68	7814.07	5738.27
Zone 6	9388.16	7760.81	11015.50	7959.90
Zone 7	13908.67	11840.30	15977.00	15931.05

Street Tree Numbers

Street trees per meter (i.e. the number of street trees in each municipality divided by the summed length in meters of streets expected to contain street trees for each municipality) is a metric which has been used in this study to estimate street tree numbers statewide. Accordingly, the number of street trees surveyed in each test inventory municipality was divided by the summed length in meters of streets expected to contain street trees for each test inventory municipality to calculate a street trees per meter statistic. Results from these calculations are contained in Table 6.9 and compared to zone class means in Table 6.10 with values for Lima and Shortsville averaged.

Table 6.9 Street trees per meter for test inventories

	Unadilla	Greene	Lima	Shortsville	Great Neck Plaza
Street Trees Inventoried	449	410	577	368	715
Street Length (meters)	13605	15676	14297	9596	10772
Trees/Meter	0.0330	0.0262	0.0404	0.0383	0.0664

Table 6.10 Street trees per meter for test inventories and zone class

	Zone Class Mean	90% UCL	90% LCL	Test Inventories
Zones 3 + 4	0.0285	0.0342	0.0228	0.0330
Zone 5	0.0323	0.0363	0.0283	0.0262
Zone 6	0.0486	0.0546	0.0426	0.0394
Zone 7	0.0710	0.0809	0.0611	0.0664

Test inventory values for Zones 3 + 4 and Zone 7 fall within zone class upper and lower 90% confidence levels. Test inventory values for Zone 5 and Zone 6 do not fall within zone class upper and lower 90% confidence levels. However, as illustrated in Figure 6.10, the trend for test inventory values approximates the trend for the zone class means with values increasing from Zones 3 + 4 to Zone 7. Therefore, while test inventory statistics for street trees per meter do not agree completely with zone class level statistics, they do appear to reflect and confirm zone class level differences and trends.

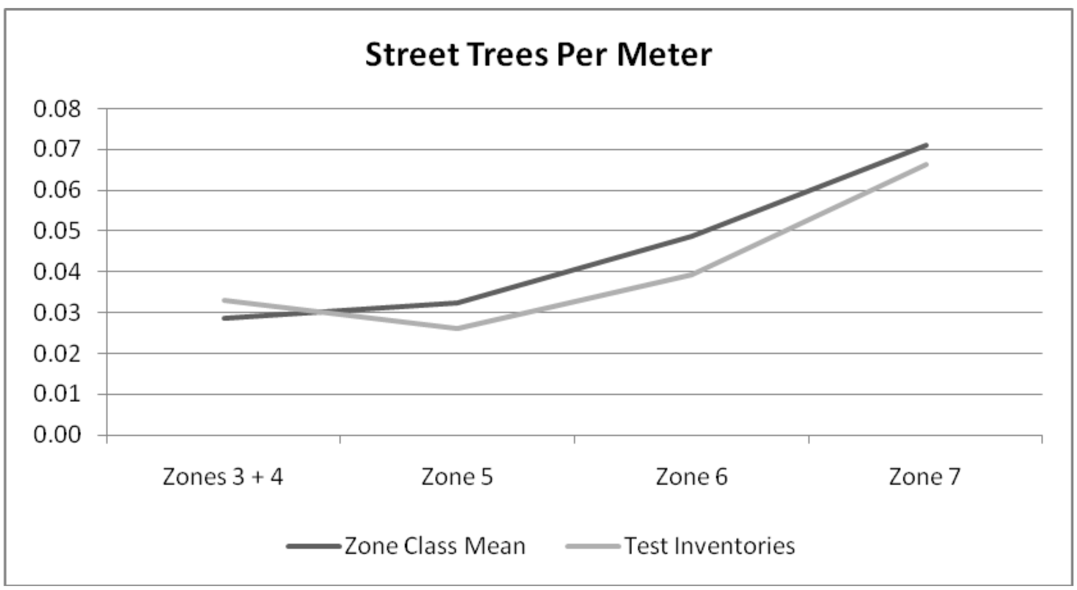


Figure 6.10 Street trees per meter for test inventories and zone class

CHAPTER 7

FINAL ESTIMATES

Data collected in the five test inventories were added to the initial sample of street tree inventory data. Calculations to generate statistics for the initial sample were updated with test inventory data included to yield final estimates.

Street Tree Numbers Statewide

Test inventory data was added to data contained in Table 3.14 to generate updated means and standard errors for street trees per meter and street trees per mile of streets expected to contain street trees by 1990 USDA Plant Hardiness Zone Class. As before, means were weighted by percentages of summed street length of streets expected to contain street trees by 1990 USDA Plant Hardiness Zone Class (Table 3.1) according to the formula:

$$((w1 * \mathrm{m}1) + (w2 * m2) + (w3 * m3) + (w4 * m4)) / (w1 + w2 + w3 + w4)$$

Updated weighted means of 0.049711904 trees per meter and 80.00300962 trees per mile were calculated. An updated standard error for the updated weighted mean was calculated according to the formula:

$$\surd\ ((se12 * w12) + (se22 * w22) + (se32 * w32) + (se42 + w42))/\ (w1 + w2 + w3 + w4)$$

Where *se*1, *se*2, *se*3, and *se*4 denote the group standard error for street trees per meter or street trees per mile of street expected to contain street trees (i.e. the standard error for each 1990 USDA Plant Hardiness Zone class). The standard error of the updated statewide weighted mean of street trees per meter of street was found to be 0.002327004 and the standard error of the updated statewide weighted mean of street trees per mile of street was found to be 3.744966561. The upper 90% confidence level of the updated weighted mean was calculated as 0.049711904 + (1.645 * 0.002327004) or 0.053539826 and the lower 90% confidence level of the updated weighted mean was calculated as 0.049711904 – (1.645 * 0.002327004) or 0.045883983. Results are contained in Table 7.1 and show a slight lowering of updated means and narrowing of confidence levels from initial means and confidence levels and a reduction of 4.86% in standard error.

Table 7.1 Initial and updated estimates for trees per meter and per mile

	Initial Estimates	Updated Estimates	Change
Trees per Meter	0.050003	0.049712	-0.59%
Standard Error	0.002440	0.002327	-4.86%
Trees per Mile	80.472553	80.003010	-0.59%
Standard Error	3.926838	3.744967	-4.86%
90% UCL (meters)	0.054017	0.053540	-0.89%
90% LCL (meters)	0.045989	0.045884	-0.23%
90% UCL (miles)	86.932201	86.163480	-0.89%
90% LCL (miles)	74.012904	73.842540	-0.23%

Based on the updated measures and 83,392,547 meters of street length expected to contain street trees (Table 2.6), final estimates of street tree numbers statewide can be calculated in meters as follows:

Tree Numbers = 83,392,547 meters * 0.049711904 trees/meter = 4,145,602

Trees 90% UCL = 83,392,547 meters * 0.053539826 trees/meter = 4,464,822

Trees 90% UCL = 83,392,547 meters * 0.045883983 trees/ meter = 3,826,382

Results are contained in Table 7.2 and show a slight lowering of estimates for street tree numbers statewide (e.g. the initial estimate of 4,169,904 street trees statewide has been updated to 4,145,602 street trees statewide). At the same time, the range in confidence intervals has been reduced by 4.86% reflecting the reduction in standard error.

Table 7.2 Initial and updated estimates for street tree numbers statewide

	Initial Estimates	Updated Estimates	Change
Trees	4,169,904	4,145,602	-0.59%
90% UCL	4,504,629	4,464,822	-0.89%
90% LCL	3,835,180	3,826,382	-0.23%
Range	669,449	638,440	-4.86%

Street Tree Numbers Statewide for Prevalent Species and Genera

Test inventory data was added to the initial sample used to calculate statewide mean percentages and 90% confidence intervals for prevalent street tree species and genera. Updated statewide weighted mean percentages were calculated for prevalent species and genera according to the formula:

$$((w1 * m1) + (w2 * m2) + (w3 * m3) + (w4 * m4)) / (w1 + w2 + w3 + w4)$$

Where $m1$, $m2$, $m3$, and $m4$ denote the group means for each species and genus (i.e. the mean percentages for each1990 USDA Plant Hardiness Zone class for each species and genus) and $w1$, $w2$, $w3$, and $w4$ denote the different weights for each group (i.e. percentages of summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places for 1990 USDA Plant Hardiness Zone classes in New York State) as stated in Table 3.1.

Updated standard errors for the statewide weighted mean percentages were also calculated according to the formula:

$$\sqrt{}\ ((se1^2 * w1^2) + (se2^2 * w2^2) + (se3^2 * w3^2) + (se4^2 + w4^2))/ (w1 + w2 + w3 + w4)$$

Where *se*1, *se*2, *se*3, and *se*4 denote the group standard errors for each species and genus (i.e. the standard error of mean percentages for each 1990 USDA Plant Hardiness Zone class for each species and genus). Updated results for prevalent street tree species are contained in Table 7.3 and updated results for prevalent street tree genera are contained in Table 7.4. Mean percentages have changed slightly from initial estimates, although the amount of change varies by species and genus. For example, with respect to genus, the mean percentage of *Acer* statewide has been updated to 44.27% from the initial estimate of 44.14%, an increase of 0.31%; the mean percentage of *Quercus* statewide has been updated to 7.015% from the initial estimate of 7.026%, a reduction of 0.15%; and the mean percentage of *Fraxinus* has been updated to 3.42% from the initial estimate of 3.35%, an increase of 2.09%. With respect to species, the mean percentage of *Acer platanoides* statewide has been updated to 20.85% from the initial estimate of 20.65%, an increase of 0.95%; the mean percentage of *Platanus x acerifolia* statewide has been updated to 5.59% from the initial estimate of 5.72%, a reduction of 2.45%; and the mean percentage of *Gleditsia triacanthos* has been updated to 5.18% from the initial estimate of 5.21%, a reduction of 0.55%.

Table 7.3 Updated statewide mean percentages, standard errors, and 90% confidence levels for prevalent New York State street tree species

Species	Mean	Std Err	90% UCL	90% LCL
Acer platanoides	20.85	1.07	22.61	19.09
Acer saccharum	9.96	0.63	11.01	8.92
Acer saccharinum	5.67	0.67	6.77	4.58
Platanus x acerifolia	5.59	0.75	6.82	4.35
Acer rubrum	5.22	0.42	5.90	4.53
Gleditsia triacanthos	5.18	0.48	5.98	4.39
Pyrus calleryana	5.02	0.72	6.21	3.83
Quercus palustris	2.98	0.35	3.55	2.40
Tilia cordata	2.73	0.29	3.20	2.26
Malus species	2.47	0.21	2.82	2.12
Fraxinus pennsylvanica	2.08	0.22	2.44	1.72
Quercus rubra	1.66	0.13	1.88	1.44
Picea abies	1.25	0.14	1.48	1.02
Pinus strobus	1.04	0.17	1.31	0.76
Robinia pseudoacacia	1.04	0.15	1.28	0.79

Table 7.4 Updated statewide mean percentages, standard errors, and 90% confidence levels for prevalent New York State street tree genera

Genus	Mean	Std Err	90% UCL	90% LCL
Acer	44.27	2.34	48.13	40.42
Quercus	7.02	0.51	7.85	6.18
Platanus	5.65	0.73	6.85	4.44
Pyrus	5.55	0.82	6.91	4.20
Gleditsia	4.94	0.46	5.69	4.19
Tilia	4.07	0.38	4.70	3.44
Fraxinus	3.42	0.27	3.86	2.98
Picea	2.95	0.27	3.39	2.51
Prunus	2.89	0.22	3.25	2.53
Malus	2.50	0.23	2.88	2.12
Pinus	1.59	0.17	1.87	1.30
Ulmus	1.31	0.20	1.64	0.98
Robinia	1.03	0.16	1.29	0.77

Based on the updated measures and the updated estimates of street tree numbers statewide, updated estimates of street tree numbers statewide for prevalent street tree species and genera can be calculated as follows:

Number of Trees = 4,145,602 trees * (Species or Genus) Mean%

Trees 90% UCL = 4,464,822 trees * (Species or Genus) 90% UCL

Trees 90% LCL = 3,826,382 trees * (Species or Genus) 90% LCL

For example, the updated estimated number of *Fraxinus* (Ash) street trees statewide could be estimated as follows:

Fraxinus Trees = 4,145,602 trees * 3.4216% = 141,848

Fraxinus 90% UCL= 4,464,822 trees * 3.8644% = 172,538

Fraxinus 90% LCI = 3,826,382 trees * 2.9789% = 113,984

Based on this methodology, updated estimates have been calculated for mean number of trees and upper and lower 90% confidence levels for prevalent street tree species and genera. Updated estimates for prevalent street tree species are contained in Table 7.5 and updated estimates for prevalent street tree genera are contained in Table 7.6. As with mean percentages for prevalent street tree species and genera, street tree numbers for prevalent street tree species and genera have changed slightly from initial estimates, although the amount of change varies by species and genus. For example, with respect to genus, street tree numbers of *Acer* statewide have been updated to 602,169 from the initial estimate of 615,068, a reduction of 0.28% and street tree numbers of *Fraxinus* have been updated to 141,848 from 139,881, an increase of 1.41%. With respect to species, street tree numbers of *Acer platanoides* statewide have been updated to 864,374 from the initial estimate of 861,226, an increase of 0.37%, and street numbers of *Pyrus calleryana* statewide have been updated to 208,142 from the initial estimate of 196,721, an increase of 5.81%.

Table 7.5 Updated estimates of tree numbers for prevalent street tree species

Species	**Mean**	**90% UCL**	**90% LCL**
Acer platanoides	864,374	1,009,698	730,314
Acer saccharum	413,004	491,360	341,304
Acer saccharinum	235,259	302,473	175,066
Platanus x acerifolia	231,549	304,673	166,332
Acer rubrum	216,292	263,481	173,469
Gleditsia triacanthos	214,805	266,840	167,845
Pyrus calleryana	208,142	277,311	146,572
Quercus palustris	123,435	158,621	91,920
Tilia cordata	113020	142,668	86,366
Malus species	102,501	125,993	81,241
Fraxinus pennsylvanica	86,278	108,956	65,894
Quercus rubra	68,895	84,014	55,179
Picea abies	51,742	66,065	38,897
Pinus strobus	42,938	58,365	29,245
Robinia pseudoacacia	42,936	57,296	30,156

Table 7.6 Updated estimates of tree numbers for prevalent street tree genera

Genus	Mean	90% UCL	90% LCL
Acer	1,835,323	2,148,710	1,546,540
Quercus	290,832	350,515	236,481
Platanus	234,087	305,949	169,923
Pyrus	230,182	308,323	160,681
Gleditsia	204,743	254,135	160,161
Tilia	168,573	209,695	131,475
Fraxinus	141,848	172,538	113,984
Picea	122,386	151,375	96,194
Prunus	119,746	145,160	96,648
Malus	103,598	128,386	81,213
Pinus	65,712	83,619	49,642
Ulmus	54,301	73,282	37,436
Robinia	42,751	57,527	29,618

For most prevalent street tree species and genera, updated mean percentages, tree numbers, and their respective upper and lower 90% confidence levels have changed slightly from initial estimates. For some street tree species and genera, the change from initial estimates has been more substantial and primarily reflects susceptibility to volatility in Zone 7 which has the fewest number of inventories relative to the other zone classes. It is likely, although not certain, that updating existing sample inventory data with additional inventory data from Zone 7 would reduce volatility and improve estimate precision. Overall, however, the addition of test inventory data has confirmed and even improved the reliability of initial estimates with updated estimates generally reflecting reductions in standard error and in the range of upper and lower 90% confidence levels for 12 of 15 prevalent street tree species and 10 of 13 prevalent street tree genera.

Statewide Annual Benefits Provided by Street Trees

Test inventory data was added to the initial sample used to calculate mean annual benefits per street tree and estimate statewide annual benefits provided by street trees. Updated mean annual benefits per street tree were calculated to be 134.15 dollars with a median of 135.61, a standard deviation of 24.05, a standard error of 2.13, and upper and lower 90% confidence levels of 137.65 and 130.66. Results contained in Table 7.7 show a slight increase in the updated mean and in the upper and lower 90% confidence levels from the initial mean and confidence levels and a reduction of 2.01% in standard error.

Table 7.7 Initial and updated estimates for statewide annual benefits ($) per street tree

	Initial Estimates	**Updated Estimates**	**Change**
Mean	133.75	134.15	0.30%
Median	135.57	135.61	0.03%
Standard Deviation	24.05	24.05	0.00%
Standard Error	2.17	2.13	-1.97%
90% UCL	137.32	137.65	0.24%
90% LCL	130.18	130.66	0.36%

The updated mean for annual benefits per street tree was used to estimate updated statewide annual benefits provided by street trees and updated upper and lower 90% confidence levels.

Estimates are as follows:

Statewide Annual Benefits = 4,145,602 trees * $134.15/tree = $556,148,138

Benefits 90% UCL = 4,464,822 trees * $137.65/tree = $614,584,569

Benefits 90% LCL = 3,826,382 trees * $130.66/tree = $499,944,101

Results are contained in Table 7.8 and show a slight reduction in estimates for statewide annual benefits from the initial estimate of $557,724,660.00, a 0.28% decrease. At the same time, the range in the upper and lower 90% confidence levels has been reduced by 3.92% reflecting a reduction in standard error of 1.97%.

Table 7.8 Initial and updated estimates for statewide annual benefits ($) provided by street trees

	Initial Estimates	**Updated Estimates**	**Change**
Annual Benefits	557,724,660.00	556,148,138	-0.28%
90% UCI	618,575,654.00	614,584,569	-0.65%
90% LCI	499,263,732.00	499,944,101	0.14%
Range	119,311,922	114,640,468	-3.92%

Estimate Sensitivity to Change in Data

Using “final” to describe the estimates that have been made above is to a great extent a misnomer since data are continually changing. Not only are new street tree inventories being conducted and existing inventories being revised, but other measures intrinsic to estimate calculations are subject to change as well. For example, the New York State ALIS (Accident Location Information System) street centerline files obtained from the New York State GIS Clearinghouse which significantly impact estimates of street trees numbers statewide, street tree benefits statewide, and prevalent street tree species and genera are revised at least once a year, were revised four times in 2010, and have been revised two times in 2011 as of this writing. Table 7.9 shows the number and types of changes to the ALIS street centerline files in 2010 and 2011.

Table 7.9 Changes to ALIS street centerline files for 2010 and 2011

New York State Street Changes	Addition	Deletion	Geometry Modification	Attribute Modification
June 2011	2579	470	565	532
March 2011	152	159	711	6249
December 2010	4647	1332	2666	2346
September 2010	3441	923	1308	2122
June 2010	10375	2647	2953	2425
March 2011	444	200	104	4892
Total	21638	5731	8307	18566

Similarly, the number and boundaries of New York State Census Places and of Census Blocks with a population density of at least 500 ppsm not contained within Census Places have changed between the 2000 United States Census and the 2010 United States Census. These changes are a product of both updated population estimates and a redrawing of Census geographies. With respect to population estimates, population in New York State grew by 2.1% between 2000 and 2010, but change was not uniform; the Western New York economic region had a 3.1% population loss while the Mid-Hudson and Capital District economic regions had a 5.1% and 4.8% population gain (Vink 2011). In turn, population changes at all geographic levels, including cities, villages, CDPs, and Census Blocks, predicate changes in the geographies associated with those levels (Francis 2011). For example, Figure 7.1 shows changes near Utica, NY for Census Blocks with a population density of at least 500 ppsm between the 2000 United States Census (left) and the 2010 United States Census (right). It is important to note that while the street layout overall has not changed, the apportionment of streets within these Census Blocks has changed which in turn will likely produce a change in the summed street length associated with them.

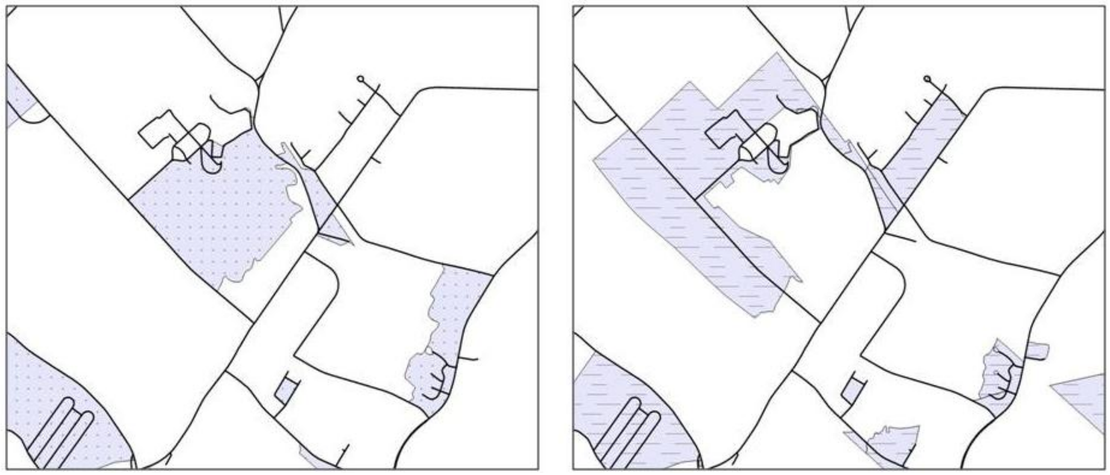


Figure 7.1 Changes in Census Block boundaries near Utica, NY between the 2000 United States Census (left) and the 2010 United States Census (right)

Because change is a constant, the methodologies employed in this research have been designed to accommodate it in so far as the methods used to derive initial estimates from the sample of 142 street tree inventories and to derive the final estimates incorporating data from the five test inventories can be applied to changes in New York State street tree inventory data, changes in New York State ALIS street centerline files, and changes in New York State Census geographies and data. It is likely, although not certain, that the addition of new street tree inventory data and the revision of existing street tree inventory data, especially if new inventory data is located in a 1990 USDA Plant Hardiness Zone class such as Zone 7 which contains fewer street tree inventories relative to the other classes, will contribute to improved reliability and precision in estimates by reducing standard error associated with tree species and genera prevalence. Less clear is the impact on estimates from changes in ALIS street centerline files and changes in Census geographies and population data affecting summed street length of streets expected to contain street trees for all Census Places and Census Blocks with a population density of at least 500 ppsm not contained within Census Places.

To assess the impact on estimates from the changes in New York State ALIS street centerline files and in Census geographies, ALIS street centerline files revised in June 2011 were obtained from the New York State GIS Clearinghouse. The same methods employed in Chapter 2 (Figure 2.2) were used to select a file of June 2011New York State streets expected to contain street trees. This file is the broadest possible measure of such streets in that these streets have not been differentiated by Census Places or those Census Blocks with a population density of at least 500 ppsm not contained within Census Places. A comparison made between the 2010 and 2011 versions of this file indicated that statewide summed street length increased from 199,307,142 meters to 199,810,568 meters, or by 0.25%. Next, a file was created of 2010 New York Census Places and 2010 Census Blocks with a population density of at least 500 ppsm not contained within Census Places. This file was then used to overlay the file of June 2011New York State streets expected to contain street trees. Streets intersecting the 2010 Census geographies were selected, apportioned to their respective 1990 USDA Plant Hardiness Zone Class, and the street lengths summed. Results are contained in Table 7.10 and are compared to the sums contained in Table 3.1.

Table 7.10 Summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places in New York State

		Zones 3 + 4	**Zone 5**	**Zone 6**	**Zone 7**	**Total**
Street Length Expected to Contain Street Trees Contained Within Census Places and Census Blocks	2010	7671805	22280970	25145460	28294312	83394557
	2011	7090931	20071573	26567598	28294312	82303090
Percentage of Statewide Total	2010	9.20%	26.72%	30.15%	33.93%	
	2011	8.62%	24.39%	32.28%	34.72%	
Percent Change		-7.57%	-9.92%	+5.66%	+0.98%	-1.31%

The statewide 1.31% decrease in street length for Census Places and Census Blocks is surprising, particularly since statewide summed street length for all streets expected to contain street trees including those not contained within Census Places and Census Blocks increased by 0.25%. Because overall street length statewide appears to have increased and changes to the New York State ALIS street centerline files for 2010 and 2011 (Table 7.9) indicate more than 3 times the number of additions than deletions, it is unlikely that changes to the ALIS street centerline files between 2010 and 2011 would account for the decrease in Table 7.10. It is much more probable that changes in Census geographies between 2000 and 2010, including an increase in the number of CDPs from 435 to 572, revisions in Census Block boundaries, and updated population estimates, account for the decrease. This appears to be confirmed by using the file of 2010 New York Census Places and 2010 Census Blocks with a population density of at least 500 ppsm not contained within Census Places to overlay the 2010 and 2011 versions of New York State streets expected to contain street trees and selecting from both versions streets intersecting the 2010 Census geographies. A comparison of these overlays found a 0.18% increase for summed selected street length between the 2010 and 2011 street files which approximates the overall statewide increase between 2010 and 2011 and diverges from the results contained in Table 7.10.

In addition to the statewide 1.31% decrease in street length for Census Places and Census Blocks, changes have also occurred within the four 1990 USDA Plant Hardiness Zone classes. For example, the statewide percentage of summed street length of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places has decreased by 9.92% for Zone 5 and increased by 5.66% for Zone 6. Because these statewide percentages have been used to calculate weighted means and standard errors of the weighted means for many measures in this research including street trees per meter of street, street tree numbers statewide, prevalent street tree species and genera percentages, and street tree numbers statewide for prevalent street tree species and genera, the changes in the zone class percentages for summed street length of streets expected to contain street trees intersecting Census geographies are likely to impact estimates for these measures.

Finally, estimates in this research have incorporated the 1990 USDA Plant Hardiness Zones for New York State. As stated in Chapter 2, an updated version of the 1990 USDA Plant Hardiness Zone map drafted in 2003 by the American Horticultural Society was rejected by the USDA and the 1990 USDA Plant Hardiness Zone Map has been used in this research. However, if as expected an updated version of the Plant Hardiness Zone Map is published by the USDA in 2012, zone boundaries will likely change and these zone boundary changes will significantly impact most measures in this research, potentially to a greater extent than the changes cited above in population estimates and Census geographies.

CHAPTER 8

REPLICABILITY OF RESEARCH METHODS

The focus of this research is to “see the forest” of New York State’s publicly managed street trees on a statewide basis. Impetus has been supplied by the need to protect the financial investments made in these trees and preserve the benefits they provide by managing them more effectively in part to meet the challenges posed by invasive pest species and climate change. These goals and challenges are not unique to New York State. Therefore, it has been an important component of this research to identify methods that are applicable not only to New York State, but can be replicated by other states as well.

Estimates made in this research are based on the following measures:

(i) Summed street length of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places

(ii) Means for street trees per meter and street trees per mile of streets expected to contain street trees

(iii) Mean percentages of prevalent street tree species and genera

(iv) Mean annual benefits per street tree

These measures are primarily dependent on two types of data: street tree inventory data and street centerline files selected, first, by street type attributes including Feature Class Codes (FCC) and, second, by Census geographies. Replicability of research methods by other states is reliant on availability of these data. Because 1990 USDA Plant Hardiness Zone class was found the best predictor variable in the statistical model, research method replicability is reliant on this data as well. Finally, facility with the computer software used to manipulate the data is also required. These issues will be addressed below.

Street Tree Inventory Data

This research was conceived on the premise that, if a sufficient number of street tree inventories could be assembled and if these inventories were broadly distributed geographically, the data from these inventories could provide an accurate understanding of the structure, functions, and trends of publicly managed street trees in New York State. Sample validity was initially assessed on the basis of 142 street tree inventories which comprised 12.92% of New York State cities, villages, and CDPs including 41.94% of New York State cities, 17.47% of New York State villages, 0.21% of New York State towns, and 2.99% of New York State CDPs (Table 2.2). By comparison, Indiana’s 2008 Sample Urban Statewide Inventory (SUSI) study was based on street tree inventory data from twenty-three municipalities of which eighteen were cities and five were towns (Davey Resource Group 2010A). The 2010

Unites States Census TIGER/Line files identify 118 cities, 113 CDPs, and 450 towns in Indiana. Therefore, the SUSI study is comprised of 3.38% of the 2010 Indiana Census Places including 15.25% of Indiana cities and 1.11% of Indiana towns. It is likely that additional municipalities in Indiana possess street tree inventories and that these inventories were not included in the SUSI study. Nevertheless, it would seem at face value, based on the number of street tree inventories assembled, that New York State is better supplied with street tree inventories than Indiana to provide an accurate understanding of the structure, functions, and trends of publicly managed street trees statewide.

However, because 1990 USDA Plant Hardiness Zone class was found to be the best predictor variable in New York State's statistical model and was used to stratify data and weight summary statistics, it is not merely the number of street tree inventories statewide that must be considered but their distribution relative to the 1990 USDA Plant Hardiness Zone classes. In other words, if a statistically significant effect on statewide street tree populations is found for 1990 USDA Plant Hardiness Zones, then the assembled inventories must be distributed evenly enough so that there are sufficient inventories for each zone or zone class. Moreover, the greater the number of zones or zone classes, the greater the number of inventories that will need to be assembled. States with fewer zones or zone classes will require fewer inventories than states with more zones or zone classes. Again, by way of comparison, while there are five 1990 USDA Plant Hardiness Zones in New York State and four zone classes were used to generate statistical estimates, there are two 1990 USDA Plant Hardiness Zones in Indiana, Zone 5 and Zone 6. Without analyzing data from the twenty-three SUSI inventories, it is unknown whether a statistically significant effect would be found on the Indiana street tree population for its two 1990 USDA Plant Hardiness Zones. If a statistically significant effect was found on the Indiana street tree population for the two 1990 USDA Plant Hardiness Zones, it would appear from the distribution of the SUSI street tree inventories shown in Figure 8.1 where seventeen inventories are associated with Zone 5 and six inventories are associated with Zone 6 that additional inventories would need to be assembled from municipalities in Zone 6.

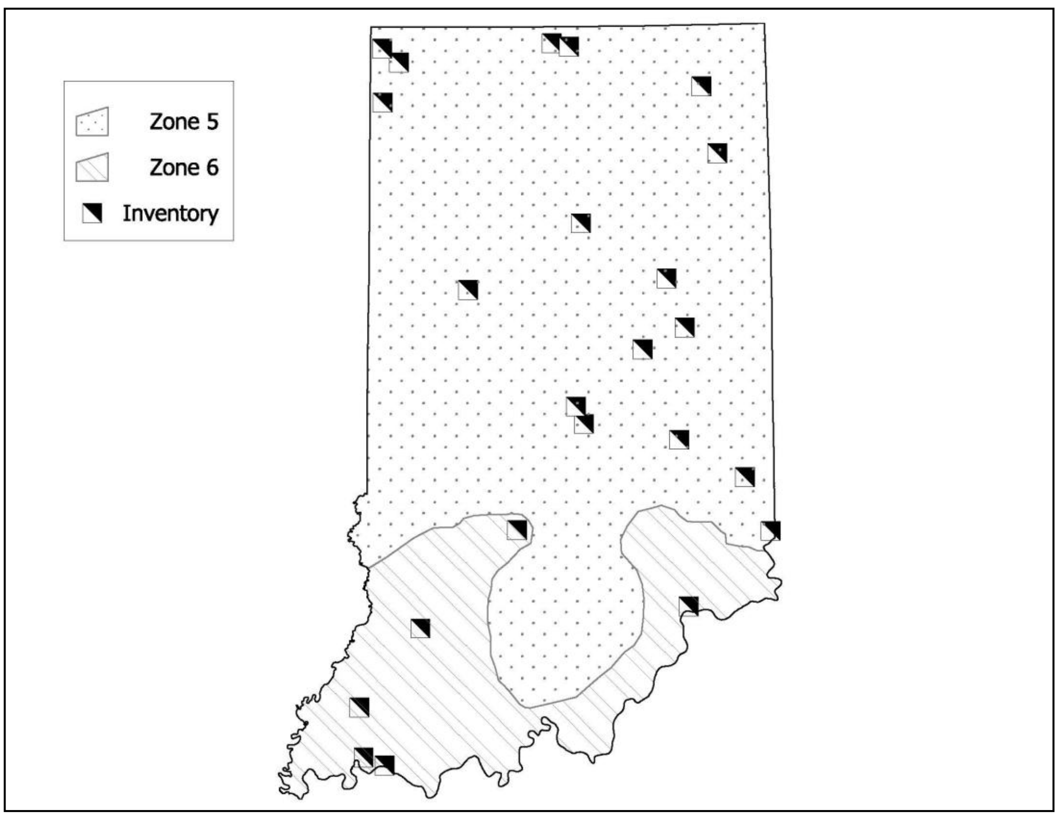


Figure 8.1 Distribution of street tree inventories included in Indiana's 2008 Sample Urban Statewide Inventory (SUSI)

As has been stated in an earlier chapter, a street tree inventory can be expensive and time consuming to conduct and most municipalities in a state, particularly smaller sized municipalities with more modest financial resources and municipalities lacking a dedicated urban forestry professional responsible for managing public trees, have not conducted one (Maco & McPherson 2003, Green et al 1998). Initial results from seeking inventories from cities and villages in New York State indicated a lack of inventories for municipalities with populations between 20,000 and 80,000 and for municipalities in northeastern New York State. Accordingly, windshield surveys were conducted in thirteen municipalities to collect data on tree species and DBH.

It is beyond the scope of this research to investigate and analyze the extent to which other states besides New York State possess a number of street tree inventories broadly distributed geographically that is sufficient to provide an accurate understanding of the structure, functions, and trends of publicly managed street trees in those states. Given the finding of this research that, notwithstanding the funding for many years of street tree inventories statewide by the New York State Department of Environmental Conservation’s Urban and Community Forestry program, additional windshield surveys needed to be conducted to promote sample validity, It can be assumed that most states do not possess a sufficient number of street tree inventories broadly distributed geographically and therefore need to obtain additional data. Because lack of sufficient street tree inventory data in other states limits replication of this study's research methods by those states, facilitating the collection of street tree inventory data should be considered an integral component in research method replicability.

Windshield surveys have been judged to be a quick, economical, and reliable way to collect many types of street tree data (Rooney et al 2005), and were conducted as part of this research. However, the most comprehensive and accurate data, and particularly data geo-referenced to specific locations, are typically collected in a walking survey. The primary impediments to a walking survey are time and cost, especially for smaller sized municipalities with more modest financial resources. Therefore, a less costly way to conduct a walking survey would facilitate the collection of street tree inventory data sufficient to provide an accurate understanding of the structure, functions, and trends of publicly managed street trees statewide. The street tree inventory model developed by Cornell University's Student Weekend Arborist Team (SWAT) provides such a way.

In 2002, a work team of Cornell University faculty, Extension educators, and urban forestry professionals in New York State perceived that smaller communities with limited personnel and funds at their disposal were underserved in community forestry planning. To address this problem, the work team devised a master planning process for smaller communities that included training a group of Cornell University students to collect street tree inventory data in a walking survey using handheld Personal Digital Assistant computers (PDAs). These students, undergraduates and graduates who had taken courses in tree species identification, became the Student Weekend Arborist Team (SWAT), so named because they would inventory communities entirely in one or two weekend days. SWAT was piloted in September 2002 with thirteen students inventorying two villages. All street trees and potential planting spaces in the public right-of-way were counted. Students were paid $80 for each day worked and earned one academic credit. The data was analyzed and street tree management plans were written. The pilot project was judged a success and SWAT has been repeated every fall with a new group of Cornell students trained each year. Forty street tree inventories have been conducted since 2002. Although data is collected by non-professionals, data accuracy has been found to be at least on par with error rates found in Bloniarz and Ryan (1996) and Cozad et al (2005) for street tree inventory data collected by volunteers. Data has also been geo-referenced and put into GIS since 2004.

Cornell University is New York State's land grant institution and SWAT was conceived from its start to be part of Cornell's land grant mission to translate university-based knowledge into real-life, practical benefits for New York State communities. There are more than 100 other land grant institutions in the United States. Many of these institutions have horticulture and/or landscape architecture departments offering courses on woody plant identification, some have urban forestry programs, and many are associated with Extension systems that train master gardeners. An opportunity exists, therefore, in many states to partner land grant institutions with Extension systems to train students and master gardeners to conduct street tree inventories. This has been done in several instances (Prochaska & Hoffman 2010, Weisman 2009), but not in a systematic or statewide manner. Although student pay has been raised to $100 for each day worked, the SWAT model still provides a low-cost approach to collect accurate street tree inventory data in a walking survey and, if adopted by land grant institutions in other states, could facilitate collection of data sufficient to provide an understanding of the structure, functions, and trends of publicly managed street trees in those states.

Street Centerline Files

New York State ALIS (Accident Location Information System) street centerline files obtained from the New York State GIS have been an integral component in generating statewide estimates of street trees numbers, street tree benefits, and prevalent street tree species and genera. These files are freely available and were used in place of United States Census Bureau TIGER/Line street centerline files because (1) the New York State ALIS files are drawn at a more accurate scale (1:24,000) and are more positionally accurate (+/- 40 feet) than the TIGER/Line files (+/- 167 feet); (2) the New York State files are updated more frequently than the TIGER/Line files; and (3) the New York State files contain more specific information about street attributes and are potentially more informative than the TIGER/Line files (i.e. driveways are differentiated in the New York State files but not in the TIGER/Line files). Recognizing the positional accuracy shortcomings of TIGER/Line shapefiles, the United States Census Bureau implemented the MAF/TIGER Accuracy Improvement Project (MTAIP) in 2002 to realign and update TIGER/Line road features. In MTAIP, files voluntarily submitted by state, tribal, county, and local governments were collated with files acquired from independent contractors and a positional accuracy standard comparable to the New York State ALIS street centerline files was established (US Census Bureau 2011c). MTAIP was completed in 2008 and MAF/TIGER street centerline files were first made available in 2009.

In a study comparing the positional accuracy of TIGERLine and MAF/TIGER street centerline shapefiles, Zandbergen et al (2011) state that:

> The positional accuracy of TIGER 2009 data is much improved compared with the TIGER 2000 data, typically by at least an order of magnitude. Unless specific research requirements dictate otherwise, any application that utilizes TIGER data for any form of spatial analysis should employ the improved TIGER data and continued uses of pre-2009 TIGER data should be discouraged.

At the same time, Zandbergen et al (2011) report that:

> Despite the substantial improvement in positional accuracy, large errors are relatively common in the TIGER 2009 data, especially in rural areas ... Most of these large positional errors identified in the TIGER 2009 data are the result of remnants of the TIGER 2000 data, which have been insufficiently corrected or not corrected at all. Most of these remnants are associated with minor road segments, often in the form of T-junctions.

Zandbergen et al (2011) conclude that, while the MAF/TIGER street centerline shapefiles are more positionally accurate than TIGERLine street centerline shapefiles, “local” street centerline shapefiles such as the New York State ALIS street centerline files are likely to be more accurate than MAF/TIGER street centerline shapefiles.

However, the following must be emphasized: road location accuracy is a different issue than road length accuracy, and error in road location error does not necessarily translate into error in road length. Additionally, and perhaps more importantly to the purposes of this research and the replicability of its research methods, Lee (2009), referencing Goodchild and Gopal (1991) states that attribute accuracy in the spatial database underlying a GIS shapefile, such as a street centerline file, must be considered when evaluating the suitability of street centerline files for research purposes. In other words, while differences in road location and road length for individual road segments may not be statistically significant between the New York State ALIS street centerline shapefiles and the MAF/TIGER street centerline shapefiles, the data contained in the database underlying both shapefiles may not be equivalent.

Delineation of street types expected to contain street trees is a key component of this research and the ability to execute the methodology shown in Figure 2.2 where street types expected to contain street trees are differentiated from all street types statewide is important to the replicability of research methods. However, in implementing the MAF/TIGER Accuracy Improvement Project (MTAIP) and making available the MAF/TIGER street centerline shapefiles, the Census Bureau replaced the Census Feature Class Codes (CFCC) used before 2007 to differentiate street types with five-digit MAF/TIGER Feature Class Codes (MTFCC). According to the US Census Bureau (2010d), some CFCC codes were "collapsed" into a single MTFCC code. For example, the MTFCC S1400 code designates a "Local Neighborhood Road, Rural Road, City Street" which includes not only the old CFCC A41 street type (Local, neighborhood, and rural road, city street, unseparated), but also the A42 (Local, neighborhood, and rural road, city street, unseparated, in tunnel), A43 (Local, neighborhood, and rural road, city street, unseparated, underpassing), and A49 (Local, neighborhood, and rural road, city street, bridge) street types.

To assess the effect of these changes and their possible impact on replicability of research methods, a comparison was made between New York State ALIS street centerline shapefiles and MAF/TIGER street centerline shapefiles for

Ontario County. Located in the western part of New York State, it contains two cities and eight villages. Street types expected to contain street trees were delineated from New York State street centerline files for Ontario County according to the methodology illustrated in Figure 2.2. Selected streets from the New York State street centerline files totaled 2,724,155 meters. Street types expected to contain street trees were then delineated from the 2010 MAF/TIGER street centerline files for Ontario County (Tl_2010_36037_roads) using a modified Figure 2.2 methodology in which Secondary Road (MTFCC S1200) and Local Neighborhood Road, Rural Road, City Street (MTFCC S1400) were differentiated from other street types including Primary Road (MTFCC S1100), Vehicular Trail (MTFCC S1500), Ramp (MTFCC S1630), Service Drive (MTFCC S1640), and Parking Lot Road (S1780). Selected streets from the 2010 MAF/TIGER street centerline files totaled 3,752,656 meters, a 37.75% increase from the selected New York State ALIS street centerline files. A comparable procedure was performed for Genesee County with similar results.

The comparative analysis above indicates significant differences exist between New York State ALIS street centerline files and 2010 MAF/TIGER street centerline files where an attempt has been made to delineate street types expected to contain street trees. These differences appear due to several factors: (1) in the 2010 MAF/TIGER street centerline files, the New York State Thruway (Interstate 90) was rendered twice, once as a Primary

Road (MTFCC 1100) and once as a Local Neighborhood Road, Rural Road, City Street (MTFCC S1400) with the MTFCC S1400 portion accounting for 102,727 meters (2) MAF/TIGER MTFCC S1400 roads include unnamed streets totaling 273,654 meters, and (3) MAF/TIGER MTFCC S1400 roads contain street associated with cemeteries, hospitals, race tracks, etc. that either are not included in the New York State ALIS street centerline files or have been selected out from these files when delineating street types expected to contain street trees. If the New York State Thruway MTFCC S1400 file and the unnamed MTFCC S1400 roads are deleted from the Ontario County MAF/TIGER street centerline files for street types expected to contain street trees, the summed street length of the MAF/TIGER street centerline files still represents a 23.94% increase from the summed street length of selected New York State ALIS street centerline files. It should also be noted that Ontario County TIGER/Line street centerline files for street types expected to contain street trees predating the 2007 replacement of CFCC codes with MTFCC codes represent only a 0.89% increase from the selected New York State street centerline files.

Because statistical estimates generated in this research are impacted by summed street length, obtaining the most reliable and accurate estimates of street length is critical to the validity of those estimates. For example, a 10% error in “street length expected to contain street trees” will result in a 10% error in the estimate of total number of street trees statewide. “Local” street centerline shapefiles such as New York State ALIS street centerline shapefiles are likely to be more accurate than MAF/TIGER street centerline shapefiles for New York State (Zandbergen et al (2011). Not only do the MAF/TIGER street centerline shapefiles contain uncorrected errors present in 2000 TIGERLine shapefiles, particularly with respect to minor streets forming T-junctions, but, as further analyzed by Zandbergen et al (2011), the MAF/TIGER centerline shapefiles contain many segments not contained in "local" street centerline shapefiles including private driveways and unpaved roads. The latter are of particular relevance to the accuracy of statewide estimates in this research since private driveways and unpaved roads should be excluded from "street length expected to contain street trees." Thus, the data contained in the spatial databases underlying the New York State ALIS and MAF/TIGER street centerline shapefiles may not only be inconsistent, but the significant differences existing between these databases in classifying and coding road types make difficult achieving equivalent measures for "street length expected to contain street trees" and for weights derived from summed street length aggregated by 1990 USDA Plant Hardiness Zone class.

Therefore, due to these factors and irrespective of whether the MAF/TIGER street centerline shapefiles represent an improvement over TIGER/Line street centerline shapefiles in positional accuracy, the New York State ALIS street centerline shapefiles represent a better choice than the MAF/TIGER street centerline shapefiles for the methodology employed in this research, at least as presently constituted. Consequently, replicability of research methods by other states will depend on the availability of street centerline shapefiles in those states comparable to New York State ALIS street centerline shapefiles. To assess the availability of street centerline shapefiles in other states, a random number generator was used to select numbers to be associated with Federal Information Processing Standard (FIPS) codes, a unique numerical identifier, for three states. Kentucky, Massachusetts, and New Jersey were the states selected in this manner. Inquiries were made regarding the availability of street centerline shapefiles in these states, the data contained in the databases underlying the shapefiles, and the applicability of these data to the methods employed in this research.

For Kentucky, statewide street centerline shapefiles are available from the Kentucky Geoportal, the state's GIS Data Clearinghouse and also from the Kentucky Transportation Cabinet. The database underlying these shapefiles does not contain street type codes similar to New York State's FCC codes. However, a RT_UNIQUE data field contains codes to differentiate public roads from private roads (e.g. driveways, subdivsions, trailer parks, factory entrances, etc.) and a RD_NAME data field specifies driveways, parking lots, ramps, and unnamed streets as well as Interstate highways. These two data fields could be used to delineate street types expected to contain street trees from all street types statewide.

For Massachusetts, statewide street centerline shapefiles are available from the Department of Transportation (MassDOT). The database underlying these shapefiles differentiates roads according to functional class (e.g. 0 = Local, 1 = Interstate, 2 = Principal arterial, 3 = Rural minor arterial or urban principal arterial, 5 = Urban minor arterial or rural major collector, 6 = Urban collector or rural minor collector) and contains additional attributes including associated land use that facilitate distinguishing private roads, highway ramps, rest areas, etc. from street types expected to contain street trees.

For New Jersey, statewide street centerline files are available from the state's Department of Transportation. The metadata states that these files do not include private roads. In addition, a ROUTE_SUBT (Route Subtype) data field provides a functional classification for all public roads (1 = Interstate Highway, 2 = US Highway, 3 = State Highway, 4 = Toll Road, 5 = County 500 Series Route, 6 = County 600 Series Route, 7 = Local Road).

Thus, street centerline shapefiles were found to be available for the three states surveyed. The best source for these shapefiles proved to be the state department of transportation rather than the state GIS clearinghouse. Data contained in the databases underlying these shapefiles varied from state to state. While none of the databases for the three states surveyed used the FCC codes describing street types found in the database underlying the New York State ALIS street centerline shapefiles, each state's database contained other types of data that would facilitate delineating street types expected to contain street trees from all street types statewide. However, it is important to obtain the data dictionary associated with each state's database to become familiar with file data structure and understand the ways in which the data can be worked to differentiate street types successfully. Additionally, if the data contained in the database does not facilitate delineating street types expected to contain street trees from all street types statewide, it may be possible to use TIGER/Line street centerline files predating replacement of CFCC codes with MTFCC codes since road length is the critical variable of interest and not positional accuracy.

Census Geographies

Research method replicability also depends on differentiating street types expected to contain street trees by Census Places (i.e. cities, villages, and CDPs) and Census Blocks with a population density of at least 500 ppsm not contained within Census Places (Figures 2.3 and 2.9). Boundary files for cities and villages used in this research are freely available and were obtained from the New York State GIS Clearinghouse. New York State boundary files were used in place of United States Census Bureau TIGER/Line boundary files for cities and villages because (1) similar to street centerline files, the New York State files have historically been drawn at a more accurate scale than the TIGER/Line files and (2) the New York State boundary files line up more precisely with the New York State street centerline files than do the TIGER/Line boundary files. Both the New York State and TIGER/Line boundary files for cities and villages are updated annually through voluntary reporting of boundary changes by municipalities. New York State, however, does not map CDPs or Census Blocks statewide. For this research, TIGER/Line boundary files for New York State CDPs and Census Blocks were accessed from the United States Census Bureau. Boundary files for CDPs and Census Blocks are subject to change from one decennial census to the next due primarily to changes in population counts and settlement patterns (US Census Bureau 2010d). In addition, as mentioned above in the discussion of street centerline files, between 2003 and 2008 the Census Bureau conducted the MAF/TIGER Accuracy Improvement Project (MTAIP) to improve the location accuracy of TIGER/Line files including boundary lines. As a result of MTAIP, boundary files for the 2000 Census geographies were modified prior to the 2010 Census although the statistical data from the 2000 Census associated with those geographies such as population counts did not change (US Census Bureau 2010d).

Thus, three versions spanning two decennial censuses exist for TIGER/Line boundary files for CDPs and Census Blocks. All versions of these files can be obtained for all states from the United States Census Bureau. Replicability of research methods is not impacted on the basis of availability. However, it may be impacted depending upon the version of the files that is used. Differences in results for delineating New York State street types expected to contain street trees between the 2000 Census and 2010 Census are documented in Chapter 7 (Figure 7.1). It was suggested that these differences should be attributed to updated population counts between the 2000 Census and 2010 Census and changes in Census geographies including an increase in the number of CDPs from 435 to 572 and revisions in Census Block boundaries. It is reasonable to assume that results for differentiating street types expected to contain street trees by Census Places and Census Blocks with a population density of at least 500 ppsm not contained within Census Places will be affected similarly. Therefore, replicability of research methods illustrated in Figures 2.3 and 2.9 will depend on accounting for the different versions of TIGER/Line boundary files for CDPs and Census Blocks between the 2000 Census and the 2010 Census and correctly associating the appropriate population figures with them

Furthermore, besides issues with their boundaries, Census Place types vary between states. In New York State, the 2010 Census Places include cities (62), villages (555), and CDPs (572), but not towns. In Louisiana, the 2010 Census Places include cities (69), villages (107), CDPs (169), and towns (128). In Oregon, the 2010 Census Places include cities (242), CDPs (135), and towns (9), but not villages. In Massachusetts, the 2010 Census Places include cities (53) and CDPs (191), but not villages or towns. In Pennsylvania, the 2010 Census Places include cities (57), boroughs (954), CDPs (749), municipalities (3) and one town, but not villages. Accordingly, replicability of research methods will also depend on recognizing the types of Census Places for each state, understanding the relationship of these Census Places to any other municipality types with defined boundaries existing in those states, and adapting the methodologies used in this research involving Census Place boundaries to the particular circumstances of each state.

Finally, consideration should be given to incorporating United States Census Bureau "urbanized areas" and "urban clusters" into research methods where such areas and clusters exist. The Census Bureau (2010e) defines urbanized areas as having 50,000 or more people and urban clusters as having at least 2,500 and less than 50,000 people, at least 1,500 of which reside outside institutional group quarters. Both urbanized areas and urban clusters encompass a:

> "… densely settled core of census tracts and/or census blocks that meet minimum population density requirements, along with adjacent territory containing nonresidential urban land uses as well as territory with low population density included to link outlying densely settled territory with the densely settled core."

Incorporating urbanized areas and urban clusters into research methods would be less cumbersome than selecting Census Blocks with a population density of at least 500 ppsm not contained within Census Places. In addition, it could capture streets expected to contain street trees not contained within Census Places and Census Blocks with a population density of at least 500 ppsm not contained within Census Places. However, neither urbanized areas nor urban clusters include villages or CDPs with populations of less than 2,500 people so their use could not fully replace the existing methodology involving Census Places and Census Blocks.

Figure 8.2 compares the city of Syracuse and surrounding region using, first, city boundaries and Census Blocks with a population density of at least 500 ppsm and, second, its urbanized area. The shaded portions are similar, but not exact, and the urbanized area appears to capture more area than city boundaries and Census Blocks. It is beyond the parameters of this research to judge which shaded portions are more accurate although the Syracuse urbanized area includes Onondaga Lake where streets containing street trees do not exist. Nevertheless, the use of urbanized areas and urban clusters warrants consideration for the future.

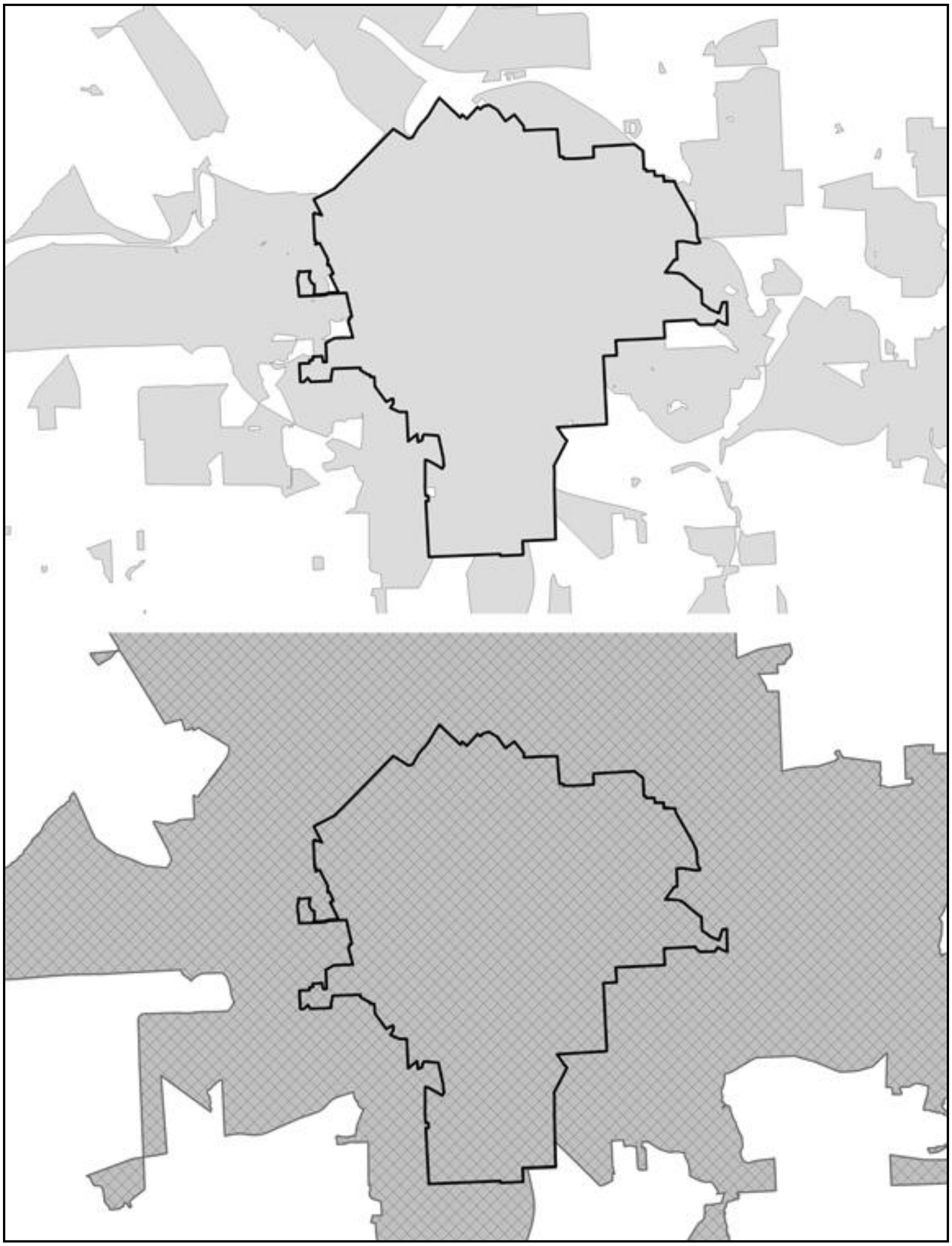


Figure 8.2 City of Syracuse; city boundaries and Census Blocks with a population density of at least 500 ppsm (top) and city boundaries and its urbanized area (bottom)

1990 USDA Plant Hardiness Zones

Plant Hardiness Zone classes for New York State derived from 1990 USDA Plant Hardiness Zone Map (US National Arboretum 1990) were found the best predictor variable in this research's statistical model. Assuming a statistically significant effect on statewide street tree populations was found for 1990 USDA Plant Hardiness Zones in other states, replicability of research methods in those states would depend on repeating, first, the methodology illustrated in Figure 2.4 where New York State zone boundaries from the Plant Hardiness Zones were digitized with GIS software; second, the methodology illustrated in Figure 2.7 where street length of New York State streets expected to contain street trees statewide and for municipalities where street tree inventory data was selected into 1990 USDA Plant Hardiness Zones, etc. Since the 1990 USDA Plant Hardiness Zone Map is available for all states and zones for each state can be digitized with GIS software, research methods pertaining to Plant Hardiness Zones are replicable on that basis. It should be noted, however, that digitizing Plant Hardiness Zones from the Plant Hardiness Zone Map is inexact from one digitizer to the next and variability in selection of communities and streets into Plant Hardiness Zones could impact replicability of estimates. Digitizing Plant Hardiness Zones is required because GIS shapefiles for the 1990 USDA Plant Hardiness Zone Map have not been made available by the United States National Arboretum. It is expected that, with the release of an updated version of the Plant Hardiness Zone Map, Plant Hardiness Zones will be made available in GIS shapefile format.

As mentioned above, the need to replicate research methods involving the 1990 USDA Plant Hardiness Zones in other states assumes that a statistically significant effect on statewide street tree populations will be found for the 1990 USDA Plant Hardiness Zones in those states. When developing the statistical model on which statewide estimates are based, statistically significant effects were found for many but not all New York State street tree species and genera for annual precipitation, elevation, distance from the equator, municipality type, LULC grid cell classes, median household income, median year structure built, and percent population with a college degree. Because 1990 USDA Plant Hardiness Zone class was found to be the best predictor variable for most prevalent street tree genera and many prevalent street tree species and effects for other variables were found to be multi-collinear with effects for 1990 USDA Plant Hardiness Zone class, these other variables were not included in the statistical model. However, while this was found for New York State, there is no guarantee that the same would be found for other states. As Figure 8.3 illustrates, the United States is characterized by distinct terrestrial biomes or ecoregions (Nature Conservancy, 2009). New York State is located within a biome characterized by “Temperate Broadleaf & Mixed Forests,” most of the Southwest states are located within a biome characterized by “Deserts & Xeric Shrublands,” and much of California is located within a biome characterized by

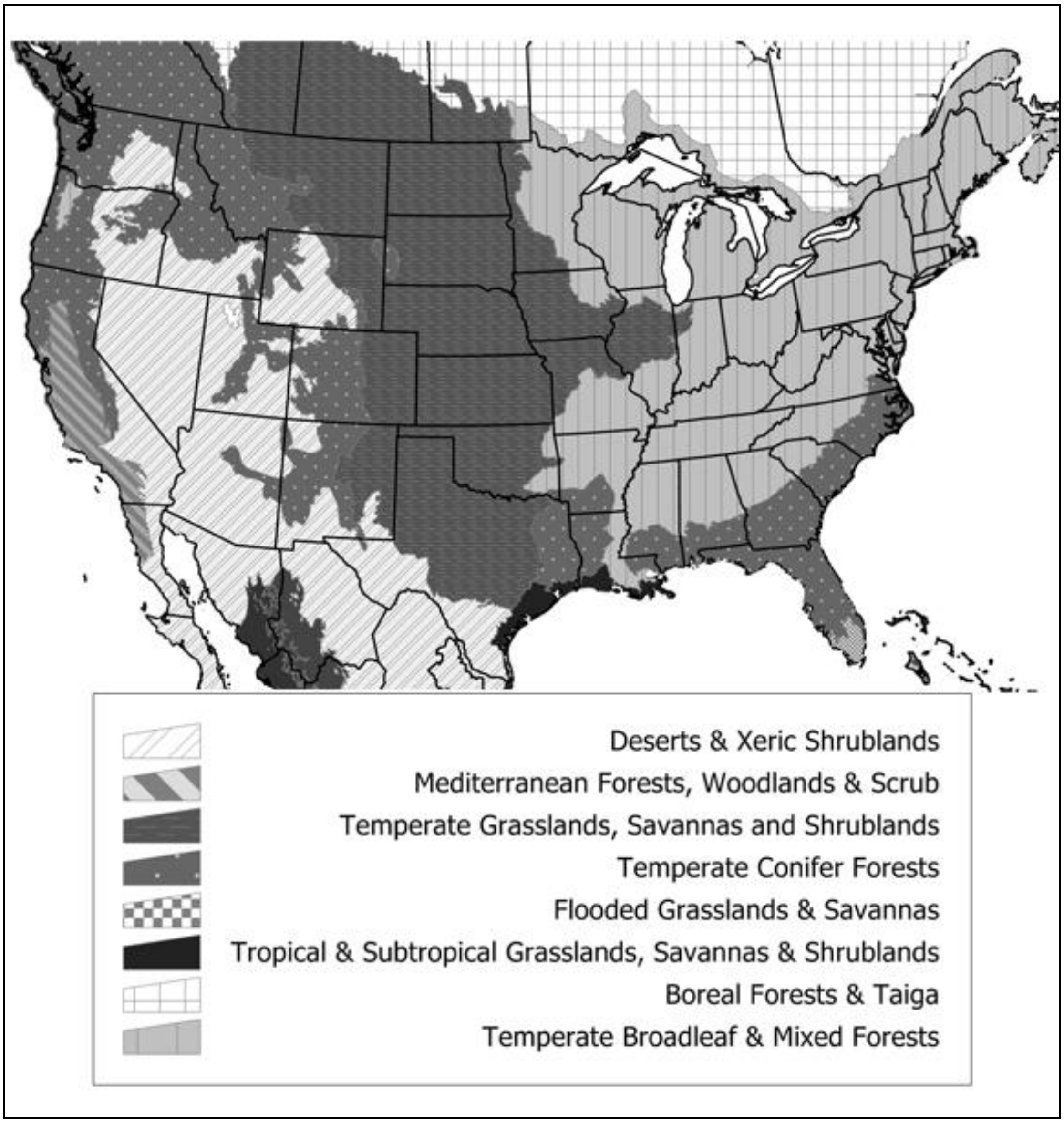


Figure 8.3 Terrestrial biomes in the United States

"Mediterranean Forests, Woodlands & Scrub." In Washington State, where the state's western part of the state receives much more annual rainfall than its eastern part due to the rain shadow effect created by the Cascade Mountain Range, annual precipitation might prove to be a better predictor variable than the 1990 USDA Plant Hardiness Zones for prevalence of street tree species and genera. In Michigan, Pennsylvania, and other states located in the same biome as New York State, the 1990 USDA Plant Hardiness Zones, or the updated version when released, might prove to be the variable with the most explanatory power. In short, if similar research is conducted in another state, the 1990 USDA Plant Hardiness Zones should not be assumed to have explanatory power similar to New York State and the same exploratory process undertaken in Chapter 4 to develop a statistical model for New York State will need to be undertaken for that state as well.

Computer Software

Finally, replicability of research methods depends on the ability to use the computer software programs used in the research to manipulate and analyze the data. These software programs include three types: statistical software, Geographic Information Systems (GIS) software, and United States Forest Service i-Tree software. Discussion of each type follows.

The statistical software programs used in this research were JMP and PAST. JMP is a statistical program created by the SAS Institute. The JMP 8 version of the program was used to run regression analyses for the statistical model. The program is easy to use and available free of charge on Cornell University computers and inexpensively via academic license. PAST is a statistical program originally aimed at paleontology but now also used in other fields.

The PAST 1.89 version of the program was used to calculate species diversity indices for New York State street trees. The program is easy to use and available free of charge via the Internet (http://folk.uio.no/ohammer/past, Hammer et al 2001). In addition to JMP and PAST, Microsoft Excel was used to calculate the weighted means, standard errors of the weighted means, and 90% Upper and Lower Confidence Levels for estimates in this research.

The GIS software programs used in this research were ArcGIS and Manifold GIS. ArcGIS is a GIS program created by ESRI. The ArcMap 9 and ArcMap 10 versions of the program were used to delineate street types expected to contain street trees from all street types statewide and to differentiate street types expected to contain street trees by Census Places and Census Blocks with a population density of at least 500 ppsm not contained within Census Places. Manifold GIS is a GIS program created by Manifold Software Limited. The Manifold 8 version of the program was used to analyze street tree inventory data and to apportion this data to the 1990 USDA Plant Hardiness Zones associated with their respective municipalities. ArcGIS and Manifold GIS are available free of charge on Cornell University computers. Additionally, ArcGIS is made available to Cornell students via an annual academic license and Manifold GIS is made available free of charge to Cornell students. Both ArcGIS and Manifold GIS require some training for their use.

United States Forest Service i-Tree software programs were used to calculate benefits provided by street trees. STRATUM (Street Tree Resource Analysis Tool for Urban-Forest Managers) was initially released in 2006 and succeeded by Streets in 2009. These programs are available free of charge from the United States Forest Service. While i-Tree software is not difficult to use and can be customized, it does require at a minimum data on tree species and DBH and the formatting of all data in very specific ways.

Based on the discussion above, replicability of research methods should not be impacted by the availability of the computer software programs used in this research. However, replicability may be impacted by the degree of facility in the use of these programs and, in particular, in the use of the GIS programs which require some training for their use.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

The objective of this research has been to “see the forest” of publicly managed trees in New York State. Research has been predicated on the assembly of street tree inventory data from municipalities statewide and the analysis of this data via methods replicable by other states. Based on this analysis, estimates have been generated for measures of interest to state officials in planning and managing urban and community forests, especially its street tree component, on a statewide basis. Additionally, trends have been identified in the state’s street tree population to further inform their planning and management on statewide and local levels. The conclusions and recommendations that follow are based upon the analyses of data and identification of trends made in this research.

Green Infrastructure

Green infrastructure has been defined as “an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations” (Benedict & McMahon 2002). Unlike the traditional concept of “infrastructure” that focuses on the physical scaffolding of a city such as roads, sewers, and power lines that facilitates urban life, green infrastructure focuses on urban green space as a system and emphasizes the ecosystem functions that this urban green space performs. The urban forest is an integral part of green infrastructure and, in terms of ecosystem function, is arguably its most influential component. As a result, great effort has been made over the past two decades to analyze urban forest functions and the benefits it provides as a natural and human resource. Urban trees have been found, for example, to remove air and water pollutants (Brack 2002), reduce storm water runoff (Xiao et al 1998), mitigate the urban heat island effect (Akbari et al1992), sequester carbon (Nowak & Crane 2002), promote wildlife diversity (Fernandez-Juricic 2000), increase real estate values (Anderson & Cordell 1988), and promote human health and well-being (Takano et al 2002). The greater the amount of urban tree cover, the greater the ability of urban trees to beneficially impact the urban environment (Nowak & McPherson 1993), bolster resilience to anthropogenic disturbance (Pickett et al 2001), and perform as green infrastructure.

Statistics in this research indicate small sized tree species have been and are being planted in increasing numbers relative to large and medium sized tree species in New York State streetscapes not only below electric utility wires, but also where utility wires are not overhead and where planting volumes are adequate to support large and medium sized trees. It has been found that a mature large sized tree costs about twice as much annually to maintain as a mature small sized tree, but that a mature large sized tree provides up to eight times as many benefits and a mature medium sized tree provides up to four times as many benefits as a mature small sized tree (McPherson et al 2002). Even if the spacing between small tree species is reduced and the number of small tree species planted in a streetscape is double the number of large tree species planted in an equivalent space, the amount of benefits provided by the mature large tree species will be nearly four times the benefits provided by the small tree species (Sydnor & Subburayalu 2011). Therefore, large and medium sized trees contribute more to green infrastructure (i.e. they do more to reduce stormwater runoff, improve air quality, mitigate the urban heat island effect, sequester carbon, and increase property values) than do small sized trees on both a gross and net cost basis.

If green infrastructure and the ecosystem and social benefits provided by street trees are identified as priorities by New York State, greater emphasis should be given to educating municipalities and the general public regarding the greater benefits provided by large and medium sized trees as compared to small sized trees and to encourage the planting of large and medium sized trees where planting volume is adequate and electric utility wires are not overhead. Failure to reverse the current trend in planting more small sized trees relative to planting large and medium sized trees will reduce the statewide structural potential of street trees to provide ecosystem and social benefits and their ability to function as green infrastructure. Because the trend towards increased plantings of small sized street tree species relative to large and medium sized tree species is not unique to New York State, but has been found in other states, the need to educate municipalities and the general public about the differences in benefits provided by small, medium, and large sized trees applies to these states as well If green infrastructure and the provision of ecosystem and social benefits are deemed a priority.

Species Diversity

In his book, *Republic of Shade: New England and the American Elm*, Campanella (2003) states that American Elms (*Ulmus americana*) were so overplanted on United States streetscapes that they were “loved to death.” In other words, American Elms were planted in such large numbers along streets in the United States that the resulting lack of species diversity in street tree plantings facilitated the spread of Dutch elm disease and magnified the impact of Elm fatalities.

Statistics in this research indicate that lessons learned from overplanting American Elms and the devastation wrought by Dutch elm disease have not been learned well enough in New York State, especially in municipalities with smaller populations that do not employ professional staff such as an urban forester. The historical overplanting of American Elms has been replaced by excessive plantings of maples, particularly upstate where the percentage of maples in some municipalities exceeds 70% of their street tree population. Because maples are a favorite host of the invasive pest species the Asian

Longhorned Beetle which kills the trees it infests and the jury is still out on efforts being made to control the ALB in New York State and other states as well, a large percentage of street trees in New York State are potentially at grave risk.

More emphasis should therefore be given to educating municipalities and the general public in New York State about the need for greater diversity in street tree plantings. This could possibly be undertaken in tandem with work already being done by County Extension and other statewide entities to increase public awareness about the threat posed to ash trees by the Emerald Ash Borer, another invasive pest species. Because municipalities with smaller populations that do not employ an urban forester have been found to be more prone to a lack of diversity in street tree plantings, efforts in this regard should be targeted to these municipalities. However, reducing the prevalence of Norway and Sugar Maples through increased plantings of Red Maples will not reduce the risk posed to the statewide street tree population by the ALB. Diversity must therefore be stressed at the level of genus and not at the level of species. Moreover, since this research has identified significant differences in species and genus prevalence on a geographic basis (i.e. by 1990 USDA Plant Hardiness Zone class), efforts to increase public awareness about the need for increased diversity in street tree plantings can be tailored geographically. For example, if reduced plantings of maples are called for, this message can be targeted to upstate municipalities since maples are found in greater abundance upstate relative to municipalities downstate. Similarly, if reduced plantings of *Platanus* are called for, this message can be targeted to municipalities downstate since *Platanus x acerifolia* is not hardy in the colder areas of New York State and *Platanus* have not been found upstate to be planted abundantly.

Data Standardization

Ideally, standardized data for street tree variables in New York State and the environmental and social variables with which it might be correlated would be available for all data at the most discrete geographic scales. This is not the case in New York State, especially for street tree data. Data coverage varies meaningfully between inventoried municipalities and is often not standardized. DBH (trunk diameter at breast height) in particular is a field where data varies since it is collected by the inch or centimeter and by the class, the parameters of which are often inconsistent from one dataset to the next. Lack of standardization limits the amount and breadth of data that can be aggregated. Consequently, dataset numbers and coverage at more discrete geographic scales (e.g. municipality and land use type) are reduced from dataset numbers and coverage at broader geographic scales (e.g. zone class).

Improved standardization of street tree inventory data would increase the number of datasets available for analysis. Greater dataset numbers would likely lower standard error and improve estimate reliability and precision for existing analyses. It could also facilitate new analyses which at present are unable to be conducted because of insufficient datasets. For example, with greater data standardization and increased dataset numbers, variation within groups (i.e. within each 1990 USDA Plant Hardiness Zone class) could be analyzed and not simply variation between groups (i.e. between 1990 USDA Plant Hardiness Zone classes). Although the United States Forest Service is working currently to identify standards for urban forestry data collection (USDA Forest Service 2010e), New York State could take steps on its own in the meantime to promote greater standardization of street tree inventory data. For example, as a condition for a municipality receiving a grant to conduct a street tree inventory, New York State could stipulate that street trees be identified by species rather than by genus and that DBH be measured by the centimeter or inch rather than by class.

Concern may be expressed that imposing conditions on receipt of grants such as the conditions mentioned above could have a chilling effect and reduce the number of street tree inventories that might be conducted, particularly inventories conducted by volunteers. Such a possibility must be weighed against the proposition that it is in New York State's interest to have street tree inventory data meet certain minimum standards. Given that the conditions suggested would not impose an undue burden on those persons most likely to conduct an inventory, whether urban forestry professionals, DEC foresters, soil and water conservation district personnel, or students trained in tree species identification, it does not seem unreasonable, if New York State is going to pay to have a street tree inventory conducted, that some minimum standards in data collection be met, especially since the resulting improvement in data standardization could increase the accuracy of estimates generated by this research and enhance the ability of state officials to plan and manage the state’s street tree population more efficiently and effectively.

Geo-referenced Data

Hand in hand with improved data standardization is the need for additional street tree data that are geo-referenced, meaning the location of each street tree is identified by longitude and latitude coordinates. More geo-referenced street tree data would facilitate geospatial analyses such as associating each tree with a land use type, street type, street gradient, distance from city center, adjacent parcel attributes such as assessed value and year structure built, etc. Associating street tree species with land use type was performed in Chapter 4 and could potentially have been more informative if additional geo-referenced street tree data had been available. As additional GIS data becomes available at increasingly discrete scales, the opportunities for associating this data with street tree data will potentially increase as well, predicated on the availability of geo-referenced street tree data.

Mention was made in the previous section of stipulating data standardization as a condition for receipt of state grants for conducting street tree inventories and weighing any reduction in the number of street tree inventories conducted against the potential benefits from data standardization. A similar argument can be made regarding the geo-referencing of street tree inventory data.

Parallel to standardizing tree species and DBH data, New York State could stipulate that collection of longitude and latitude coordinates for each tree.as a condition for a municipality receiving a grant to conduct a street tree inventory. Because collection of longitude and latitude coordinates for each tree is more challenging than tree species identification and measuring trees with a DBH tape, stipulating such a condition could require an outside consultant, preclude participation of some municipalities in the inventory process, and have more of a chilling effect on the number of street tree inventories conducted than data standardization. To address this potential problem, tiered levels of funding could be offered with greater funding provided for geo-referenced inventories. Data accuracy would also need to be specified (i.e. the distance between each mapped data point and the tree's true location). In the most recent draft of the United States Forest Service's proposed standards for urban forestry data collection (USDA Forest Service 2010e), 100 feet is proposed as a measure of geo-referenced data accuracy. 100 feet seems too inexact, particularly since recreational grade GPS equipment is capable of locating street trees within 15 feet of their true locations and GPS waypoints can be rectified where required to aerial orthoimagery. Additionally, accuracy greater than 100 feet would give more confidence in the reliability and validity of geospatial analyses involving geo-referenced street tree locations. 30 feet is an achievable measure of geo-referenced data accuracy that could be specified by New York State.

Facilitating Additional Inventories

Discussion can be found in many fields about whether quality and quantity are independent or if there is an inherent trade-off between them (i.e. the greater the quantity produced, the lesser the quality). Such a discussion is potentially applicable to a street tree inventory. A trade-off would seem to exist between data completeness and cost effectiveness (i.e. the greater the number of data fields and the more technically demanding the data, the more time and cost involved in collecting the data). The cost of conducting a street tree inventory is an obstacle in obtaining one, especially for smaller sized municipalities with limited financial resources (Maco & McPherson 2003, Green et al 1998). Reducing inventory cost could enable a greater number of inventories to be conducted than might otherwise be the case. In turn, reducing the number of data fields and eliminating the more technically demanding data could reduce cost. However, the question to be answered is whether this less costly version of a street tree inventory is still worth conducting or if data quality has been severely compromised.

As mentioned in Chapter 1, reasons for conducting an inventory include maintenance and liability concerns (Bond & Buchanan 2006, Tate 1985) and as a planning tool for augmenting species diversity (Peper et al 2004). While these reasons are not mutually exclusive, they do involve collection of different data and require different levels of expertise. For example, evaluating species diversity in the street tree population involves collecting data for tree species and DBH (trunk diameter at breast height), a task that can be undertaken by a professional or non-professional. Evaluating maintenance and liability concerns and especially identifying hazard trees and recommending trees for removal are more technically demanding tasks often requiring recognition of defects that are not visually discernible and therefore should be undertaken only by an urban forestry professional. This distinction between levels of expertise required by different types of data was recognized in the formation of Cornell University's Student Weekend Arborist Team (SWAT). Students skilled in tree species identification did not have the expertise to recommend trees for removal and were instructed to note in the data large trees with visual defects that might potentially constitute hazards for inspection subsequent to the inventory by an urban forestry professional. Division of inventory tasks in this way facilitated conducting inventories that might ordinarily not have been conducted by reducing costs while preserving data completeness. It is a model that could be used in other states outside New York State to conduct sufficient inventories to facilitate statewide assessments.

Continued Statewide Assessment

Just as a street tree inventory is only a snapshot in time, so too is this document. As stated previously, using “final” to describe the estimates that have been made in this research is a misnomer since the data underpinning the estimates, including street tree data, street centerline files, and Census geographies, is dynamic and continually changing. Thought should therefore be given to formalizing a statewide appraisal of New York State street trees on a regular basis. In Indiana, the 2008 Sample Urban Statewide Inventory (SUSI) provided a comparison with results from another sample statewide inventory conducted in 1992. In California, periodic assessments at five year intervals have been made of the statewide street tree population based on questionnaires submitted to urban foresters statewide. Although it can be argued that the street tree inventory data assembled in Indiana provides a more reliable and valid assessment of a statewide street tree population than the questionnaire data assembled in California, periodic assessment in both states has been helpful in identifying trends over time.

Unlike many states, New York State is fortunate to possess a large number of street tree inventories broadly distributed throughout the state. The creation of a “statewide database of community tree inventories” has been cited by the state as a goal in a five year plan “to support municipalities, volunteer groups, and professional organizations in the planning and management of urban and community forests in the state" (New York State 2010). Such a database has not yet been created and it is not clear when it will be although a similar database may be created as part of the United States Forest Service's Urban Forest Health Information Center (UFORHIC). However, creation of a statewide database consisting of street tree inventory data assembled from municipalities throughout New York State would facilitate periodic assessment of the street tree population on a more reliable and accurate basis than the questionnaires used in California and more comprehensively than the twenty-three communities sampled in Indiana. In fact, if data from new inventories and updated data from existing inventories were added to the database on a timely basis, and reporting functions were written to query the database about species composition and DBH distribution, state officials would be able to track and analyze data, perhaps not in real time, but still much more frequently than the five years between reassessments in California. Such reporting would facilitate cost-effective and sustainable management of community trees at both the state and local level, provide information supporting program changes and budget requests, and help meet the challenges posed by climate change and invasive pests. Whether or not a database and reporting functions are ever created, the need for periodic reassessment of the statewide street tree population still remains. Urging state municipalities to update their street tree inventory data on a regular basis as is often done will ring hollow if New York State fails to follow suit with updating its statewide assessment.

"Scale matters"

The adage "You can't manage what you don't know" is often stated as a reason to inventory street trees since municipalities are unable to manage their street trees effectively, whether budgeting for maintenance or increasing species diversity through new plantings, without having adequate data about their street tree populations. This research has been undertaken in that vein although at a much different scale since it has focused on analyzing street tree data at the statewide level rather than at the level of the individual municipality. This statewide focus prompts another adage, "Scale matters," cited frequently in geographic research when data collected at one scale is used to make inferences about data at another scale. The importance of scale has already been raised with respect to ecologic fallacy and the caution that should be exercised in using data aggregated at a broader scale to make inferences about data disaggregated at a finer scale. However, caution should also be exercised when generalizing from the specific since findings may be scale dependent and trends found at a more discrete scale may not be seen at a broader one.

Street tree data collected at the level of the individual municipality has provided the basis for this research. This municipal level data was then aggregated at the level of the 1990 USDA Plant Hardiness Zone class and aggregated again at the statewide level. Use of the zone class was predicated by statistically significant differences identified at that level for street tree population characteristics in the sample data. Zone class was found to be the best predictor variable for these characteristics at this time. It is possible as additional street tree datasets are collected, data is increasingly standardized, standard error is reduced, and estimate accuracy is increased that other environmental and social variables could prove to be superior predictors of street tree population characteristics than 1990 USDA Plant Hardiness Zone class at both broader and finer geographic scales. This possibility additionally supports the need for continued statewide assessment.

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